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Metropolitan District Commission

Water Supply Study and
Environmental Impact Report 2020

Task 1:
Water Demand Projections

Interim Technical Report

Submitted To:
Metropolitan District Commission

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GLOSSARY

Accounted-for Water: the amount of water recorded on all consumer meters in a community, plus estimates of consumption for consumers with no meters or stopped meters.

Base Water Demand: an estimate of the future water demand of the 44 current MDC user communities which consists of forecasts for individual water use components (domestic, nondomestic, and unaccounted-for).

Capacity Planning Estimate: an estimate of the future water needs of the MDC system which consists of two separate parts: (1) base water demand for current MDC users, and (2) additional potential demand for which the MDC must plan, including legal obligations to communities, supply deficits in the potential future user communities, and potential additional demands on the MDC due to contamination of local supplies.

Demand Management: measures to reduce the total demand for water, including public education, domestic retrofit, leak detection and repair, pressure reduction, use of non-potable water, reuse and recycling of water, and rate structure changes.

Demand Simulation Model: a computer model for estimating future water demand based on projections within individual water use sectors (domestic, non-domestic, and unaccounted-for water) and different types of water use (sanitary, process, cooling, outdoor, and other).

Domestic Water Use: metered residential use of water, excluding nursing homes, colleges, hospitals, prisons, and other institutions.

DRI: Data Resources, Inc.

Eligible Communities: communities within a 15-mile radius of the State House, but outside a 10-mile radius, which according to M.G.L. Chapter 92, Section 10, are legally eligible to receive water from the MDC, if the Commission can reasonable supply them with water.

Entitled Communities: communities within a 10-mile radius of the State House in Boston which, according to M.G.L. Chapter 92, Section 10, are legally entitled to join the MDC.

Major Water Users: industries, utilities, and large institutions which use more than ten million gallons of water per year.

MAPC: Metropolitan Area Planning Council

MDC Special Users: nondomestic users supplied directly by the MDC rather than by a town water department, such as MDC parks and state institutions.

MDC System Usage: water used within the MDC's transmission and distribution system including leakage, and water used for system maintenance or lost during system repairs.

MDC User Communities: those communities currently fully- or partially-supplied with water by the MDC, including 35 member communities and 10 nonmember communities which purchase MDC water on a contractual basis.

M.E.P.A.: Massachusetts Economic Policy Analysis Model.

Metered Ratio: the ratio of accounted-for water to total water produced or purchased by a community expressed as a decimal.

MGD: million gallons per day.

MGY: million gallons per year.

Nondomestic Water Use: all metered nonresidential use of water, including institutions, industries, power plants, stores, offices, etc.

OSP: Massachusetts Office of State Planning.

Potential Future Users: communities in the planning area which are not presently served by the MDC but might reasonably be served in the future.

Revenue Meters: MDC meters which measure the quantity of water delivered to each community.

Unaccounted-for Water: the difference between the total amount of water produced or purchased by a community and accounted-for water.

Water Demand Projections: estimates of the total future demand for water in the MDC system without including estimates of potential water demand reductions which could result from demand management strategies.

Water Needs Projections: estimates of the total future need for water in the MDC system including estimates of potential water demand reductions which could results from demand management strategies.

Executive Summary

SUMMARY OF WATER DEMAND ESTIMATE FOR THE MDC

The Metropolitan District Commission (MDC) is conducting a study of the 40-year water needs of the cities and towns it is responsible for supplying. The MDC Water Division currently provides water for over two million people in 45 municipalities in metropolitan Boston and central Massachusetts.

Since 1960 the demand for water from the MDC has grown by about 30 percent. During the decade of the 1960's, water use increased because of growth in population, employment and industrial output, and stabilized in the 1970's because of population shifts and shifts away from water-intensive industries. For the past several years, the total demand on the MDC system has exceeded the amount of water that safely can be withdrawn from the sources of supply. In order to plan for the future water supply needs of its users and evaluate means of meeting these needs, the MDC undertook a long-range Water Supply Study and Environmental Impact Report.

The first step in this Water Supply Study and Environmental Impact Report is to estimate the future water needs of the MDC system for the years 1990, 2000, and 2020. This summary is a brief outline of more detailed information presented in the full report called Water Demand Projections.

Water demand is defined here as the amount of water that will be sought from the MDC in the future, unconstrained by any new demand management programs. The demand report assesses in detail all components of water use and how they may vary over time from present use (base year 1980). Subsequent work will evaluate and apply new demand management (water conservation and leakage repair) programs to reduce demand on the system. This will result in a water needs projection, as differentiated from unconstrained demand. The amount of water available in MDC's present supplies will be subtracted from the water needs projection to arrive at a final water supply amount for future planning. Various alternative water supply sources, as well as demand management and watershed management programs, are being evaluated to meet future needs.

PLANNING AREA

The analysis of future water demand includes both communities that are presently within the MDC Water District and communities that may need water from MDC sources in the future. Included in the planning area are 30 communities which are presently fully-supplied by the MDC, and 14 communities which are partially-

supplied by the MDC[1]. Also, 36 communities with potential shortfalls in local supply but which are not currently served by the MDC were analyzed as potential future users. These communities are either legally eligible to join the Metropolitan Water District or so located that they might reasonably turn to the MDC for new supply. The planning area communities are listed in Table 1, "Communities in the Planning Area".

According to statute, communities which are at least in part within a 15-mile radius of the State House and which the MDC can reasonably supply with water are eligible to become members of the Metropolitan Water District. Any community, any part of which is within ten-miles of the State House, is entitled to membership in the Metropolitan Water District. These communities are listed in Table 2, "Communities Eligible to Membership in the Metropolitan Water District". Of these eligible communities only those communities projected to face a supply shortfall were included in the planning area.

CAPACITY PLANNING ESTIMATE

It is projected that the demand on the MDC for water will be on the order of 453 million gallons per day (MGD) by 2020. The 1980 demand on the system was 343 MGD. The 2020 figure represents a 30 percent increase over the demand on the system in 1980 and is substantially less than the 142 percent by which demand increased over the previous 40 years. This capacity planning estimate incorporates the following demands on the MDC system, summarized in Table 3, "MDC Water Demand Projection":

- the projected use of the current MDC user communities (369 MGD), including special users and MDC system usage, totalled under the heading "Base Demand" in Table 3;

- legal obligations on the MDC to supply additional water to present users or to supply legally eligible communities (51 MGD); and

- possible additional users and users requiring new supply as a result of local contamination (33 MGD).

This capacity planning estimate does not incorporate estimates of potential water demand reductions which become a member of the Metropolitan Water District. could result from the water conservation strategies being studied.

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[1] Since this work was completed the City of Lynn has become a member of the Metropolitan Water District.

Table 1. Communities in the Planning Area

CURRENT USERS OF THE MDC SYSTEM

Community Users

Arlington	Stoneham	Cambridge (P)
Belmont	Swampscott	Canton (P)
Boston	Waltham	Needham (P)
Brookline	Watertown	Peabody (P)
Chelsea	Winchester (P)	Wakefield (P)
Everett	Winthrop	Weston (P)
Lexington	Chicopee *	Wellesley (N) (P)
Malden	Wilbraham *	Woburn (P)
Marblehead	Clinton *	Worcester * (P)
Medford	Melrose	Leominster * (P)
Milton	Framingham * (P)	Northborough * (P)
Nahant	Marlborough * (P)	Lynnfield Water District
Newton	Southborough *	Revere
Norwood	Quincy	South Hadley Fire District No. 1 *
Somerville	Saugus	

Special Users

Fernald School & Metropolitan State Hospital *	Westboro State Hospital *
G.S.A. *	Lynn - General Electric * (see Footnote 1)
MDC Parks Division *	
MDC Sewerage Division *	

POTENTIAL FUTURE USER COMMUNITIES

Acton °	Easton	North Reading +
Amherst	Fitchburg	Paxton
Ashland	Holden	Randolph +
Athol °	Holbrook +	Rutland °
Avon +	Hopkinton	Sterling
Bedford + °	Hudson °	Stoughton + °
Billerica +	Lancaster	Tyngsborough °
Braintree +	Lynn ° (see Footnote 1)	Ware
Brockton °	Lynnfield +	Westwood +
Chelmsford	Middleton + °	Westborough
Danvers + °	Natick +	Whitman °
Dedham +	North Andover	Wilmington + °

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* Non-member of Metropolitan Water District (Contract User)
(P) Partially Supplied
(N) Currently Takes No Supply
\+ Legally-eligible communities are at least in part within fifteen miles of the State House according to the General Laws, Chapter 92, Section 10.
° Projected to face local water supply deficits by 2020.

Table 2. Communities Eligible to Membership in the Metropolitan District

LEGALLY ENTITLED

The following communities are at least in part within ten miles of the State House and thereby entitled for membership according to the M.G.L., Chapter 92, Section 10.

Arlington *	Lexington *	Saugus *
Belmont *	Lynn °* (See Footnote 1)	Somerville *
Boston *	Malden *	Stoneham *
Braintree °	Medford *	Wakefield *
Brookline *	Melrose *	Waltham *
Cambridge *	Milton *	Watertown *
Chelsea *	Nahant *	Wellesley *
Dedham °	Needham *	Weymouth
Everett *	Newton *	Winchester *
Hingham	Quincy *	Winthrop *
Hull	Revere *	Woburn *

LEGALLY ELIGIBLE

The following communities are at least in part within fifteen miles of the State House and thereby eligible for membership according to the M.G.L., Chapter 92, Section 10, if they can reasonably be supplied with water.

Avon °	Lynnfield °	Reading
Bedford °	Lynnfield Water	Salem
Billerica °	District *	Sharon
Burlington	Marblehead *	Stoughton °
Canton *	Medfield	Swampscott *
Cohasset	Middleton °	Walpole
Concord	Natick °	Wayland
Danvers °	North Reading °	Weston *
Dover	Norwood *	Westwood °
Holbrook °	Peabody *	Wilmington °
Lincoln	Randolph °	

° Included in the Planning Area
* Currently served

Table 3. MDC Water Demand Projection (MGD)

Water Use Categories	1980	1990	2000	2020
MDC Water Use:				
Metered Domestic Water Use	143.0	138.6	136.5	141.8
Metered Nondomestic Water Use	126.1	136.9	145.0	164.9
Unaccounted-for Water Use	105.9	88.4	91.0	102.0
Subtotal	375.5[1]	363.9	372.5	408.7
Drought		5.0	5.0	5.0
Lynn Deficit [2]			0.5	2.7
MDC System Usage	30.1	21.0	21.0	21.0
Total Demand	405.6	389.9	399.0	437.4
Less Amount Supplied Locally by Partial Users	(62.5)	(62.4)	(64.3)	(68.7)
Base Demand on MDC	343.1	327.5	334.7	368.7
Additional Demand:				
Legal Obligations		50.7	51.1	50.8
Contamination		11.0	19.0	28.0
Additional Users		3.7	4.0	5.2
Uncertainty Range		365-421	371-447	388-518
Capacity Planning Estimate		393	409	453

[1] Due to disaggregation of total and adjustment of components, numbers do not add.

[2] Since this work was completed the City of Lynn has become a member of the Metropolitan Water District.

POPULATION AND EMPLOYMENT PROJECTIONS

The population and employment projections used in the demand analysis are based on the mid-range, control forecasts of the University of Massachusetts, Amherst model (the Massachusetts Economic Policy Analysis Model). This forecast represents a 12 percent increase in population to the year 2020 for the 44 currently served communities, compared to a forecast of 19.7 percent for the entire state.

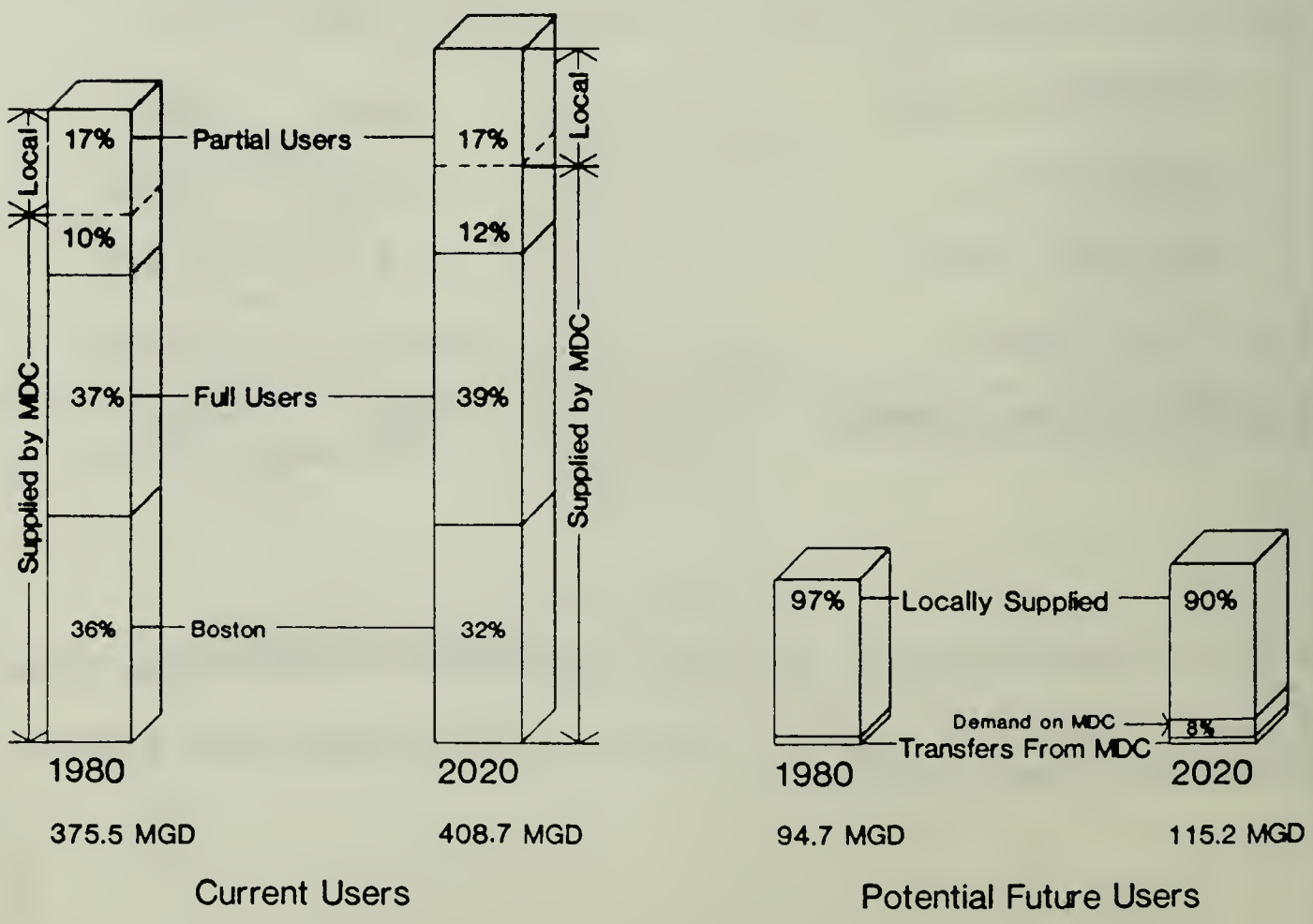
BASE DEMAND ON MDC

WATER USE COMPONENTS

The total amount of water used by communities that are currently served by the MDC was 375.5 MGD in 1980. Since some communities are only partially supplied by the MDC, the use of local supplies amounted to 63 MGD, and 313 MGD was provided by the MDC. The 36 communities which are potential future users of MDC supply consumed 94.7 MGD in 1980, a small portion of which was transferred on an emergency basis from MDC user communities. It is estimated that only 13 of these communities will actually require some water from MDC sources, totalling less than ten MGD in 2020. The water use by these communities is shown in Figure 1: "Community Water Supply by Source".

Figure 1.

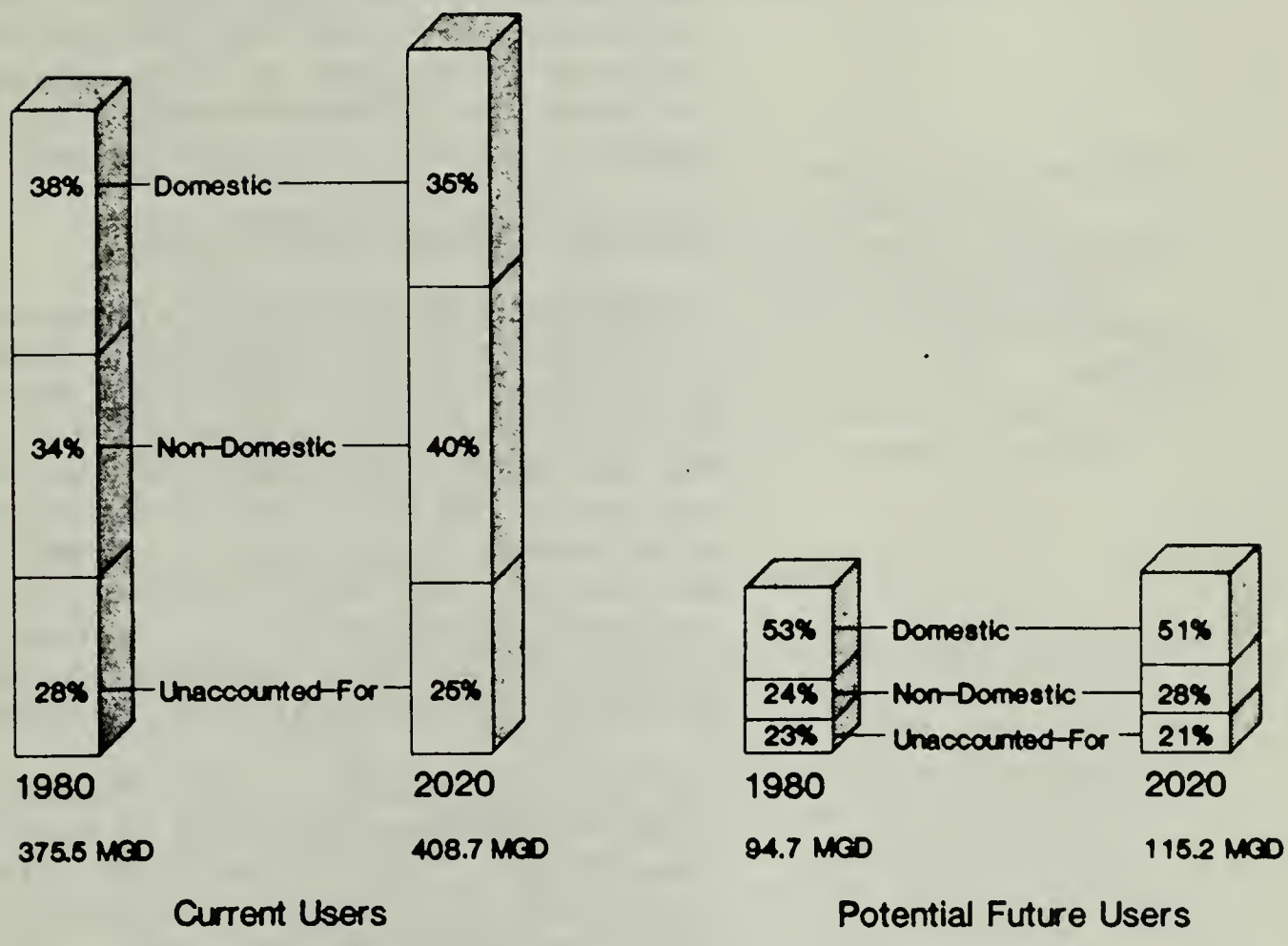
Community Water Supply by Source



Total water use in each community is made up of three components: metered domestic use, metered nondomestic use, and unaccounted-for water use. Each component represents about one-third of the total use in the 44 communities currently served by the MDC, as shown in Figure 2: "Water Use by Component".

Figure 2.

Water Use by Component



This water demand analysis projects future water need for each of these components separately in order to better assess the many factors which affect different types of use and to have better data for estimating the impact of various demand management strategies. These projections take into account current changes in water use practices and technology, such as water-saving plumbing fixtures. The projections are developed by combining projected patterns for domestic and non-domestic water use in each community and the projected changes in the number and type of users.

Metered Domestic Water Use

Metered domestic use is the metered residential use of water, excluding nursing homes, colleges, hospitals, prisons, and other institutions. This use amounted in 1980 to an estimated 143 MGD for the 44 MDC communities

and represented 38 percent of total water used by these communities. About 12 percent of this use is estimated to be outdoor seasonal use; 66 percent is bathroom related (primarily bathing and toilet flushing); and the remaining 22 percent is kitchen and laundry related.

A relatively stable amount of metered domestic use is projected for the 40-year planning period in the communities currently served by the MDC. Slight growth in domestic water use is projected for the non-MDC planning area communities. The analysis of domestic use indicates that the effect of projected population and housing increases will be generally offset by projected reductions in water consumption due to the increased use of water-saving fixtures recently mandated by the state plumbing code.

Metered Nondomestic Water Use

Metered nondomestic use is all metered nonresidential use of water, including nursing homes, colleges, hospitals, prisons, industries, power plants, stores, offices, etc. This use amounted to an estimated 126 MGD for the 44 MDC communities in 1980 and was 34 percent of the total water used by these communities. Major users, each of which consumes over 10 million gallons per year (MGY), account for about 55 percent of the total nondomestic use. Sanitary use represents 49 percent of the total nondomestic use, with the rest being cooling and industrial process use.

For metered nondomestic use, the forecasts show a slight-to-moderate increase in both MDC and non-MDC communities. This reflects the effect of moderate employment increases and substantial output increases which are offset, in part, by a shift to less water-intensive industries, such as electronic and computer manufacturing, and more efficient water and energy use practices.

Unaccounted-for Water

Unaccounted-for water includes both leakage and unmetered uses. It is the amount of water purchased by the community minus the metered water use. Elements of unaccounted-for water are:

- domestic and nondomestic meter underregistration;
- public unmetered use (fire-fighting, sewer and main flushing, street cleaning);
- potentially recoverable leakage;
- unavoidable leakage; and
- other unaccounted-for water, such as illegal connections, standpipe overflows, data processing errors, and reservoir evaporation.

Based on water use studies of MDC communities, the 1980 total unaccounted-for water for current MDC users is estimated to have been 105.9 MGD in 1980, or 28 percent of total supply.

The total amount of unaccounted-for water is expected to decline by approximately three percent by 2020 due primarily to improved meter accuracies and municipal recovery of leakage, an effort funded in part by state grants. Most of the recovery is expected by 1990 when unaccounted-for water is projected to decrease by 17.5 MGD. It is assumed that unaccounted-for water will increase to 102.0 MGD by 2020 without further intervention.

MDC System Usage

MDC system usage is water that is used within the MDC's own transmission and distribution system. This includes leakage and water used for system maintenance or lost during system repairs. While system usage amounted to 30 MGD in 1980, several major improvements and repairs occurred in that particular year. Assuming that this will not recur in any one year, 21 MGD has been selected as the projection for average system usage in the future.

ADDITIONAL DEMAND

LEGAL OBLIGATIONS

A number of communities have the legal right either by contract, membership in the District, or by statute to take an amount of water from the MDC that they are not presently taking. In planning for the future demands on the system, these obligations must be taken into account. Over the 40-year planning period conditions could change due to drought or loss of local supplies that would mean these communities would exercise their full legal rights to the water specified.

Current members of the Metropolitan Water District are entitled to take their full supply of water from the MDC, although some members are now only partially-supplied by the MDC. The full legal obligation to these members by the MDC would represent about 37 MGD above the base demand for these communities.

Some communities are not members of the Metropolitan Water District but have contracts which specify the maximum amount of water that can be taken from the MDC, and less than this contract amount is now being taken. The legal obligation of the MDC to these contract users represents approximately 15 MGD above the base demand.

Since communities within 15 miles of the State House are eligible to receive water from the MDC, the MDC

must plan for supplies to those eligible communities which are projected to face local water shortages by 2020. Less than two MGD is projected to meet this need.

CONTAMINATION

Increasingly, local water supplies have experienced incidents of contamination through which communities have lost either a portion or all of their water supply. A total of 28 MGD is incorporated into the capacity planning estimate as an additional demand on the MDC by 2020 resulting from potential new contamination of local supplies. By applying a rate of contamination to the use of local supplies, an estimate for future contamination was developed. This estimate is based on an analysis of an increasing rate of occurrence of contamination incidents and the likelihood that communities in more urbanized areas will experience a greater loss of local water supplies. The rate of contamination is expected to increase over the planning period.

ADDITIONAL FUTURE USERS

Of the 36 non-MDC potential future user communities in the planning area, 13 are projected to face water shortages that might require them to seek supplemental supplies from the MDC. The additional demand on the MDC by these potential future users would amount to approximately ten MGD by 2020 of which five is from communities which do not currently have rights to MDC supply. This assumes that they would use their local supplies to the fullest extent possible. Brockton is the largest of these additional user communities.

UNCERTAINTIES AND SENSITIVITIES

Even for a short time span, it is difficult to predict the future with complete accuracy. For a 40-year period it is even more difficult. There are uncertainties associated with each of the factors included in the estimate of water demand. As the planning period is extended, a wider range must be used as there are greater uncertainties over time. Uncertainties exist around the population and employment projections and the assumptions concerning future water use practices, as well as the conditions governing how communities utilize their local water supplies. The result is that a reasonable capacity planning estimate is 393 MGD in 1990 ± eight percent and 453 in 2020 ±19 percent.

Chapter 1.
Capacity Planning Estimate and Base Water Demand Forecasts

INTRODUCTION

The purpose of this chapter is to summarize:

- the approach used in the development of a capacity planning estimate;
- the components of domestic, nondomestic, and unaccounted-for water;
- the base demand forecasts for the current users of the MDC; and
- the forecasts of additional potential demands on the MDC.

The following chapters (2-4) outline in detail the forecasting methodology used for the three major components of water use: metered domestic, metered nondomestic, and unaccounted-for water.

THE PLANNING AREA AND RECENT WATER USE TRENDS

PLANNING AREA COMMUNITIES AND THEIR WATER USE

The planning area defines those communities for which detailed projections of water demand were done. This area provided the basis of the future demand on the MDC over the 40-year planning period. The planning area included both communities that are presently within the MDC Water District and communities that may need water from MDC sources in the future. Included are 30 communities which are fully supplied by the MDC and 14 communities which are partially supplied by the MDC. Also 36 communities with potential shortfalls in local supply but which are not presently served by the MDC were analyzed as potential future users. These communities are either legally eligible to join the Metropolitan Water District or so located that they may reasonably turn to the MDC for future supplies. Total water use in these 80 communities in 1980 amounted to 376 MGD, 313 MGD of it supplied by the MDC (See Figure 3).

Communities fully-supplied by the MDC. The fully-supplied communities include 25 MDC members of the Metropolitan Water District and 5 nonmembers that are contract users that together used 276.1 MGD of water. These 30 communities accounted for 80 percent of the water supplied by the MDC in 1980. Boston is the single largest user, accounting for 135.2 MGD, or 49 percent of the total for these communities, in 1980.

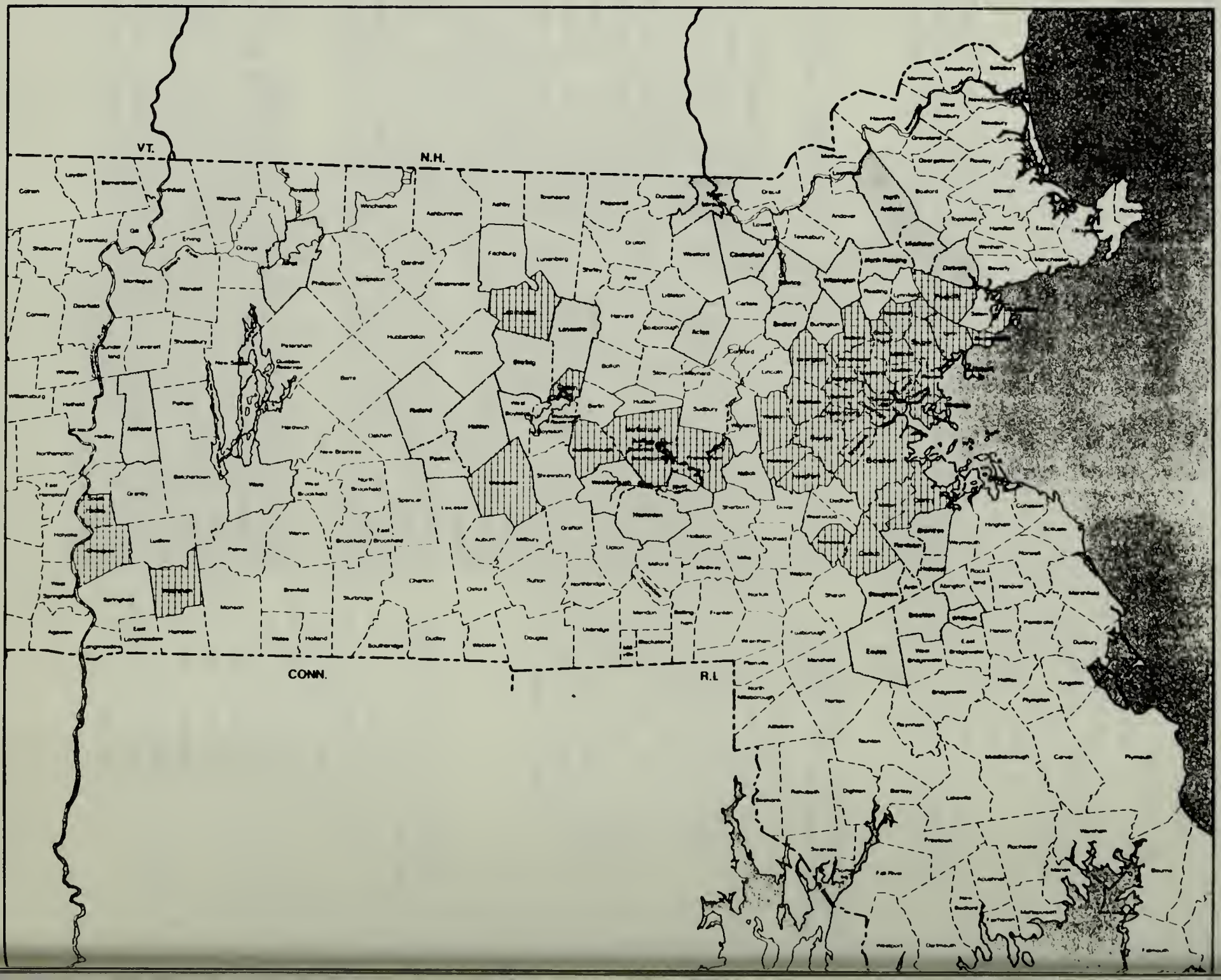


Figure 3.
Communities in the Planning Area

Legend

- Communities Currently Supplied by MDC
- Potential Future Users

0 5 10 Miles

MDC Water Supply Study and EIR 2020
Phase II

Metropolitan District Commission

Wallace, Floyd Associates, Inc.

Communities partially-supplied by the MDC. These partially-supplied communities include nine MDC members and five nonmembers. Weston, although currently fully-supplied, falls under a partial-user agreement with the MDC. Together they accounted for 25.4 MGD or 7 percent of the water supplied by the MDC in 1980. Worcester and Cambridge are the largest partial users, accounting for more than one-half of the water used by this category; however, in years of average precipitation, they are almost fully self-supplied. Framingham is the largest partially-supplied user of MDC water, consuming 33 percent of the water supplied by the MDC to these communities in 1980.

Self-supplied communities with potential shortfalls in supply. Other planning area communities include 36 communities whose total water use amounted to 94.7 MGD in 1980. Brockton and Lynn are the largest water users in this group, accounting for 29.4 MGD, or 31 percent of the water use by these communities in 1980.

Other MDC Users. Special uses of MDC water totalled 42 MGD or 12 percent of the water supplied by the MDC in 1980. These included an estimated 30 MGD for system uses, 8.5 MGD for Wachusett watershed withdrawals by surrounding communities not directly supplied by the MDC distribution system, and 3.1 MGD for special users that were supplied directly rather than by a town water department (e.g., MDC parks and state institutions, such as Westborough and Metropolitan State Hospitals).

Community Water Demands and Supplies. Since some communities are only partially-supplied by the MDC, the total amount of water used by all 80 planning area communities is greater than the MDC supply. Tables 4 and 5 tabulate the major components of use for each of the 44 MDC communities and the 36 additional planning area communities, showing both total demand and demand on the MDC (or deficit for potential future users).

RECENT WATER USE TRENDS

Recent trends in water use are reviewed in Figure 4, which shows the historical use of water by the MDC communities since 1960 and the projections to 2020. Recent trends indicate that:

- Since 1960, water supplied by the MDC has increased by about 30 percent. The total volume of water used by the 44 MDC communities has increased by about 22 percent, including use of local supplies.

- All of the increases in total water use (both MDC- and locally-supplied) by the 44 MDC communities since 1960

Table 4. Components of Water Demand for Current Use 1980 (MGY/MGD)

GROUP=FULLY SUPPLIED MDC MEMBERS

CODE	NAME	DOM80	NDOM80	UAF80[1]	DEM80	DDEM80	MDCDD80
62	ARLINGTON	1,164	143	436	1,743	4.76	4.76
63	BELMONT	681	274	151	1,106	3.02	3.02
51	BOSTON	13,050	17,623	18,821	49,499	135.24	135.24
52	BROOKLINE	1,807	315	496	2,618	7.15	7.15
141	CHELSEA	657	492	37	1,236	3.38	3.38
72	EVERETT	803	1,546	749	3,098	8.47	8.47
476	LEXINGTON	902	881	340	2,123	5.80	5.80
252	LYNNFIELD WD	79	39	42	160	0.44	0.44
71	MALDEN	1,091	554	344	1,989	5.43	5.43
418	MARBLEHEAD	570	31	190	791	2.16	2.16
81	MEDFORD	1,292	249	1,745	3,286	8.98	8.98
73	MELROSE	700	89	241	1,030	2.81	2.81
406	MILTON	621	125	345	1,091	2.98	2.98
253	NAHANT	109	17	19	145	0.40	0.40
91	NEWTON	2,196	814	1,057	4,067	11.11	11.11
361	NORWOOD	615	590	386	1,591	4.35	4.35
401	QUINCY	2,068	1,145	1,077	4,290	11.72	11.72
142	REVERE	697	151	691	1,699	4.64	4.64
254	SAUGUS	609	200	584	1,384	3.78	3.78
101	SOMERVILLE	2,414	635	537	3,586	9.80	9.80
495	STONEHAM	425	479	406	1,310	3.58	3.58
255	SWAMPSCOTT	438	51	231	720	1.97	1.97
471	WALTHAM	1,431	1,959	819	4,209	11.50	11.50
93	WATERTOWN	830	271	627	1,728	4.72	4.72
143	WINTHROP	518	130	114	762	2.08	2.08
599	XXXXXXXSUBTOTAL	35,918	28,808	30,535	95,261	260.28	260.28

GROUP=FULLY SUPPLIED NONMEMBERS

CODE	NAME	DOM80	NDOM80	UAF80	DEM80	DDEM80	MDCDD80
435	CHICOPEE	1,422	1,635	742	3,799	10.38	10.33
166	CLINTON	386	200	116	702	1.92	1.92
223	SO. HADLEY FD1	354	416	28	798	2.18	2.18
272	SOUTHBOROUGH	129	51	10	190	0.52	0.52
455	WILBRAHAM	203	70	36	309	0.84	0.84
599	XXXXXXXSUBTOTAL	2,494	2,372	932	5,798	15.84	15.79

GROUP=PARTIALLY SUPPLIED MDC MEMBERS

CODE	NAME	DOM80	NDOM80	UAF80	DEM80	DDEM80	MDCDD80
61	CAMBRIDGE	1,900	3,322	1,069	6,291	17.19	0.07
362	CANTON	585	190	334	1,109	3.03	1.45
92	NEEDHAM	769	417	141	1,327	3.63	1.08
420	PEABODY	1,171	544	1,381	3,096	8.46	2.33
74	WAKEFIELD	672	74	144	890	2.43	1.64
94	WELLESLEY	659	234	223	1,116	3.05	0.00
479	WESTON	353	57	7	417	1.14	1.14
497	WINCHESTER	620	121	351	1,092	2.98	3.04
491	WOBURN	1,068	770	614	2,452	6.70	1.06

Table 4 Continued

GROUP=PARTIALLY SUPPLIED MDC_MEMBERS

CODE	NAME	DOM80	NDOM80	UAF80[1]	DEM80	DDEM80	MDCDD80
599	XXXXXXXSUBTOTAL	7,797	5,729	4,264	17,790	48.61	11.82

GROUP=PARTIALLY SUPPLIED NONMEMBERS

CODE	NAME	DOM80	NDOM80	UAF80	DEM80	DDEM80	MDCDD80
265	FRAMINGHAM	1,725	981	447	3,153	8.61	8.42
172	LEOMINSTER	700	1,232	327	2,259	6.17	1.34
261	MARLBOROUGH	831	454	223	1,508	4.12	3.78
269	NORTHBOROUGH	173	53	24	250	0.68	0.06
501	WORCESTER	2,710	4,524	2,161	9,395	25.67	0.00
599	XXXXXXXSUBTOTAL	6,139	7,244	3,182	16,565	45.26	13.61

GROUP=OTHER MDC WATER USES

CODE	NAME	DOM80	NDOM80	UAF80	DEM80	DDEM80	MDCDD80
551	MILTON-CANTON	0	-13	0	-13	-0.03	0.00
521	SPECIAL MDC	0	1,119	0	1,119	3.06	3.06
523	SYSTEM USES	0	0	11,009	11,009	30.08	30.08
549	WACH-QPXT(WORC)	0	0	0	0	0.00	6.00
550	WACHUSETT-OTHER	0	919	0	919	2.51	2.51
599	XXXXXXXSUBTOTAL	0	2,025	11,009	13,034	35.61	41.65

GROUP=TOTAL FOR CURRENT USERS

CODE	NAME	DOM80	NDOM80	UAF80	DEM80	DDEM80	MDCDD80
599	XXXXXXXXXXTOTAL	52,348	46,178	49,922	148,449	405.60	343.14

[1] Due to slight programming differences in accounting for inter-town transfers, the unaccounted figures differ slightly from those in the text of the report.

Table 5. Components of Water Demand for Potential Future Users–1980 (MGY/MGD)

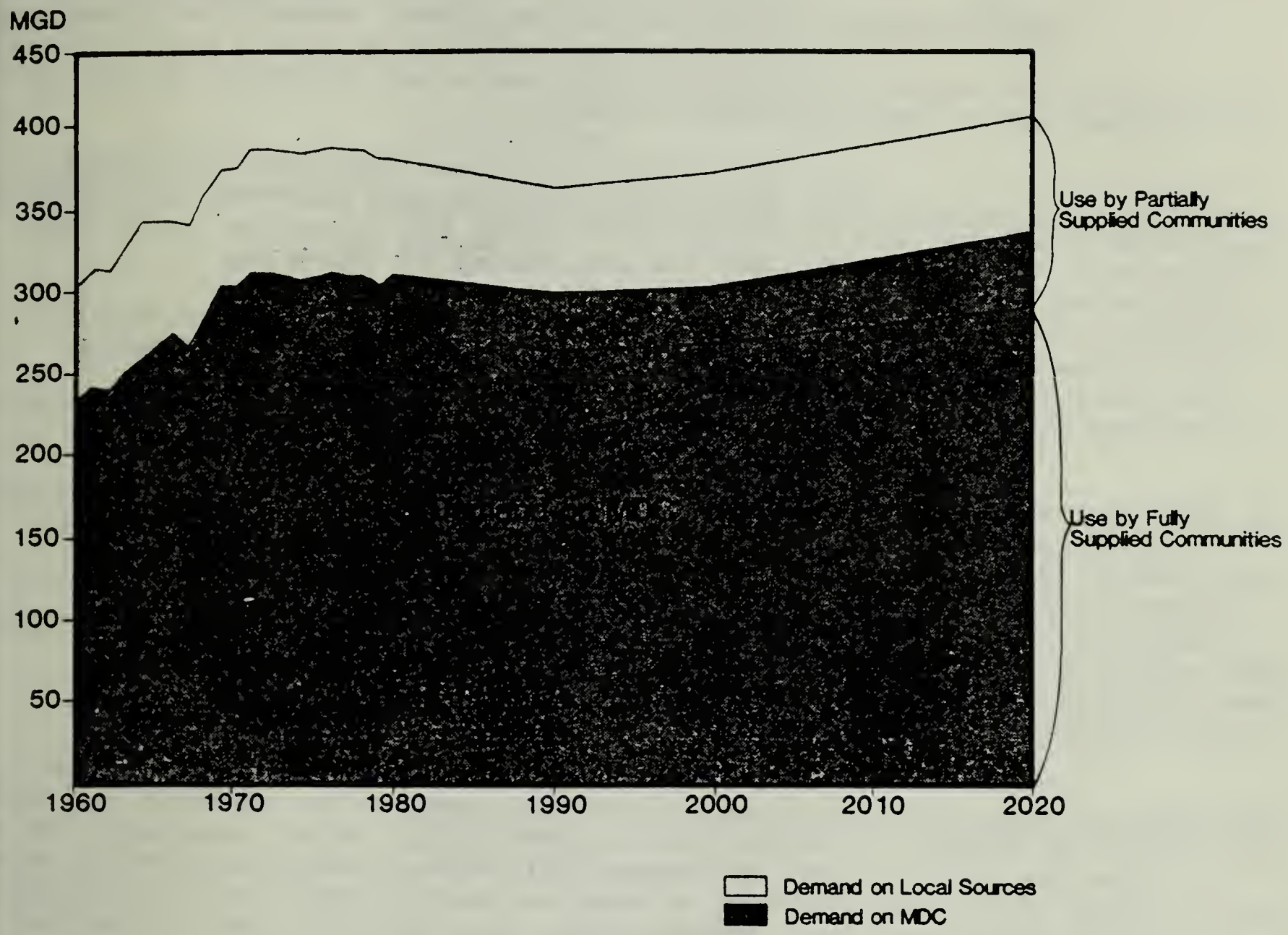
GROUP=POTENTIAL FUTURE USERS

CODE	NAME	DOM80	NDOM80	UAF80[1]	DEM80	DDEM80	DEF80
472	ACTON	355	118	54	527	1.44	0.00
342	AMHERST	525	641	24	1,190	3.25	0.00
262	ASHLAND	319	39	68	426	1.16	0.00
1	ATHOL	160	182	78	420	1.15	0.00
113	AVON	94	33	19	146	0.40	0.00
473	BEDFORD	314	198	62	574	1.57	0.00
242	BILLERICA	816	412	108	1,336	3.65	0.00
553	BILLERICA-BEDFD	0	-71	0	-71	-0.19	0.00
402	BRAINTREE	943	236	397	1,576	4.31	0.00
111	BROCKTON	2,374	859	1,855	5,088	13.90	3.40
243	CHELMSFORD	957	256	569	1,782	4.87	0.00
413	DANVERS	544	336	105	985	2.69	0.00
363	DEDHAM	459	242	325	1,036	2.83	0.00
118	EASTON	303	110	169	582	1.59	0.00
161	FITCHBURG	806	1,066	961	2,833	7.74	0.00
123	HOLBROOK	206	69	50	325	0.89	0.00
507	HOLDEN	300	48	181	529	1.45	0.00
287	HOPKINTON	155	43	11	209	0.57	0.00
266	HUDSON	443	78	281	802	2.19	0.00
170	LANCASTER	148	15	37	200	0.55	0.00
251	LYNN	3,214	1,607	852	5,673	15.50	0.98
522	LYNNFIELD CWD	181	4	28	213	0.58	0.00
419	MIDDLETON	60	50	13	123	0.34	0.00
268	NATICK	994	163	472	1,629	4.45	0.00
234	NORTH ANDOVER	653	163	32	848	2.32	0.00
493	NORTH READING	216	24	119	359	0.98	0.00
514	PAXTON	69	1	11	81	0.22	0.00
130	RANDOLPH	582	213	161	956	2.61	0.00
515	RUTLAND	58	22	9	89	0.24	0.01
177	STERLING	114	16	25	155	0.42	0.00
133	STOUGHTON	672	74	132	878	2.40	0.42
248	TYNGSBOROUGH	136	26	36	198	0.54	0.54
490	WARE	220	47	70	337	0.92	0.00
518	WESTBOROUGH	374	198	169	741	2.02	0.00
370	WESTWOOD	252	131	175	558	1.52	0.00
135	WHITMAN	197	65	29	291	0.80	0.80
496	WILMINGTON	321	482	240	1,043	2.85	0.00
552	XFROM MDC USERS	0	-1,079	0	-1,079	-2.95	0.00
599	XXXXXXXXXXTOTAL	18,544	7,117	7,927	33,588	91.77	6.15

[1] Due to slight programming differences in accounting for inter-town transfers, the unaccounted figures differ slightly from those in the text of the report.

Figure 4.

Historic and Projected Base Demand for Water by Current Users



occurred during the 1960s, with total use since 1970 declining slightly. Total community water used in 1980 represents a decline of about 4 percent from the 1971-1972 peak. Water use declined by an additional 3 percent in 1981.

- The growth in water use during the 1960s generally matched the growth in total employment and industrial output in the region but occurred at a much higher rate than for housing and population.

- The total community use of water was relatively constant during the 1970s. During this period, employment and industrial output increased substantially, with housing increasing slightly and population decreasing slightly.

- While water use on a per capita basis increased during the period from 1960 to 1980, it is projected to decline over the planning period.

There are many explanations for these shifts in water-use patterns.

- During the 1960s, domestic water use increases resulted from increases in both housing and population, and these were compounded by increasing use factors (e.g. water use per household, per capita, per employee, per unit of output) associated with more water-using appliances. Industrial/commercial water use increased during this period due to substantially increased employment and output, but only moderate efforts to adopt new energy- or water-saving technologies.

- During the 1970s, domestic use of water was relatively stable with the effect of increased housing units being offset by decreased population. During this period, it is estimated that domestic water use factors stabilized, as the installation of additional water-using appliances moderated and as the availability of water-saving fixtures and appliances increased. Industrial/ commercial water use also stabilized as substantial increases in employment and output were offset by shifts away from water-intensive industries, and by the fact that many major users adopted water- and energy-saving technologies. Unaccounted-for water also declined slightly as communities initiated leakage recovery programs and meter replacement programs.

THE CAPACITY PLANNING ESTIMATE AND FORECASTING METHODOLOGY

COMPONENTS OF THE CAPACITY PLANNING ESTIMATE

The capacity planning estimate for use in planning long-term improvements to the MDC supply system consists of two separate parts:

An Estimate of Base Water Demand for Users of the Current MDC System. This estimate was derived from a water demand simulation model developed specifically for this study. It consists of forecasts of individual water use components (domestic, nondomestic, and unaccounted-for) for each of the current 44 MDC communities and Lynn (a member as of January 1, 1983), plus forecasts of special users and system usage, less the expected use of local supplies by partial MDC users.

The base water demand estimate incorporates population and employment forecasts developed by the University of Massachusetts/Amherst; an analysis of trends in water use by over 400 individual major users and groups of smaller users -- both domestic and nondomestic; an assessment of changing water use practices, regulations, and technologies for different types of water use. It also includes a small adjustment to reflect increased use of MDC-supplied water during extended drought periods.

An Estimate of Additional Potential Demands for Which the MDC Must Plan. This includes an estimate of the additional amount of water which the MDC is legally obligated to supply; forecasts of potential water supply deficits in the 36 potential future user communities in the planning area which the MDC may have to meet; and estimates of potential additional demands on the MDC due to the contamination of local supplies. The legal obligations arise from (1) the statutory requirements governing the MDC and (2) contractual arrangements with individual towns. The forecasts of water supply deficits were based on the outputs of the demand simulation model for the 36 non-MDC communities, less their potential use of their local supplies, as surveyed by the Department of Environmental Management from the local water superintendents' estimates of the 1990 safe yields. The estimate of potential additional demands due to contamination of local supplies was derived by applying contamination factors ranging from 5 to 20 percent, based on an analysis of historic trends, to the forecast use of local supplies by communities which could reasonably be served by the MDC.

The estimate of additional potential demands also includes an assessment of the uncertainties in water use forecasts associated with forecasts of growth and water use factors.

The estimates of these uncertainties represent the findings of an analysis of alternative assumptions and forecasts of population and economic growth and water use factors. The demand simulation model was used to assess the impact of these uncertainties on the three forecast components of base water demand -- domestic, nondomestic, and unaccounted-for water. The range is estimated to incorporate 95 percent of the uncertainties associated with the growth and water use factors in 1990, 90 percent in 2000, and 85 percent in 2020.

FORECASTING METHODOLOGIES

The Water Demand Simulation Model. Projections of municipal water use traditionally have been based on a simple formula in which future use was the product of projected population times projected water use per capita. Water use per capita has been an increasing factor historically. While traditionally water use has been related to population, other factors are important in influencing water consumption patterns. The MDC sought to reflect the complexity of consumption patterns in undertaking this study of more detailed estimates of water use.

Because of the wide variety of water uses and the significant shifts now taking place in many of the factors affecting water use, the MDC sought a disaggregated approach to projecting demand in order to develop and assess the potential water savings of a long-range demand management program and more accurately assess future water demand. A demand simulation model was therefore developed and used to derive water use forecasts based on detailed assessments of factors affecting water use and the potential demands on the MDC system. The base demand forecasts of domestic and nondomestic water described in this report represent the output of this model. Forecasts of unaccounted-for water were developed separately and incorporated into the model.

Forecasts of base water demands on the MDC supply system were based on (1) assessments of recent and long-term trends in water use; (2) characterizations of water use components and relationships; and (3) estimates of likely changes in water-using activities and water-use practices and technologies that are thought likely to occur in the future.

The effects of these factors were traced through different types of water use (sanitary, process, cooling, outdoor, other), different categories of water users (domestic, industrial, commercial/institutional, public, and other), and different types of communities (fully-supplied by MDC,

partially-supplied by MDC, and others potentially served by MDC) to develop base water demand forecasts. The organization of the model is schematically shown in Figure 5.

- Demand was broken down into the major components of use to reflect those factors which affect different types of water use. Large users (e.g., selected industries, utilities, large institutions) were examined individually.

- The model built upon current use patterns in each community and simulated changes in community water use as a function of changes in the number and types of users and altered water use practices and technology. Thus, the projections were not based on "average" community characteristics but were based on an attempt to characterize individual community water use.

- The model incorporated changes in water use practices and technology and was not a simple extrapolation of past usage trends. For example: wastewater treatment regulations have significantly affected industrial water use through discharge restrictions; higher energy prices have promoted water conservation with home appliances or industrial equipment designed to use less hot water; and the newly adopted plumbing code requires low water-using toilets and low-flow showerheads for both new construction and replacements.

- The model permitted assessment of uncertainty by simulating water use under alternate assumptions or scenarios. Thus the methodology allowed for the uncertainty inherent in forecasts--of future population, economic growth, and estimates of water use factors.

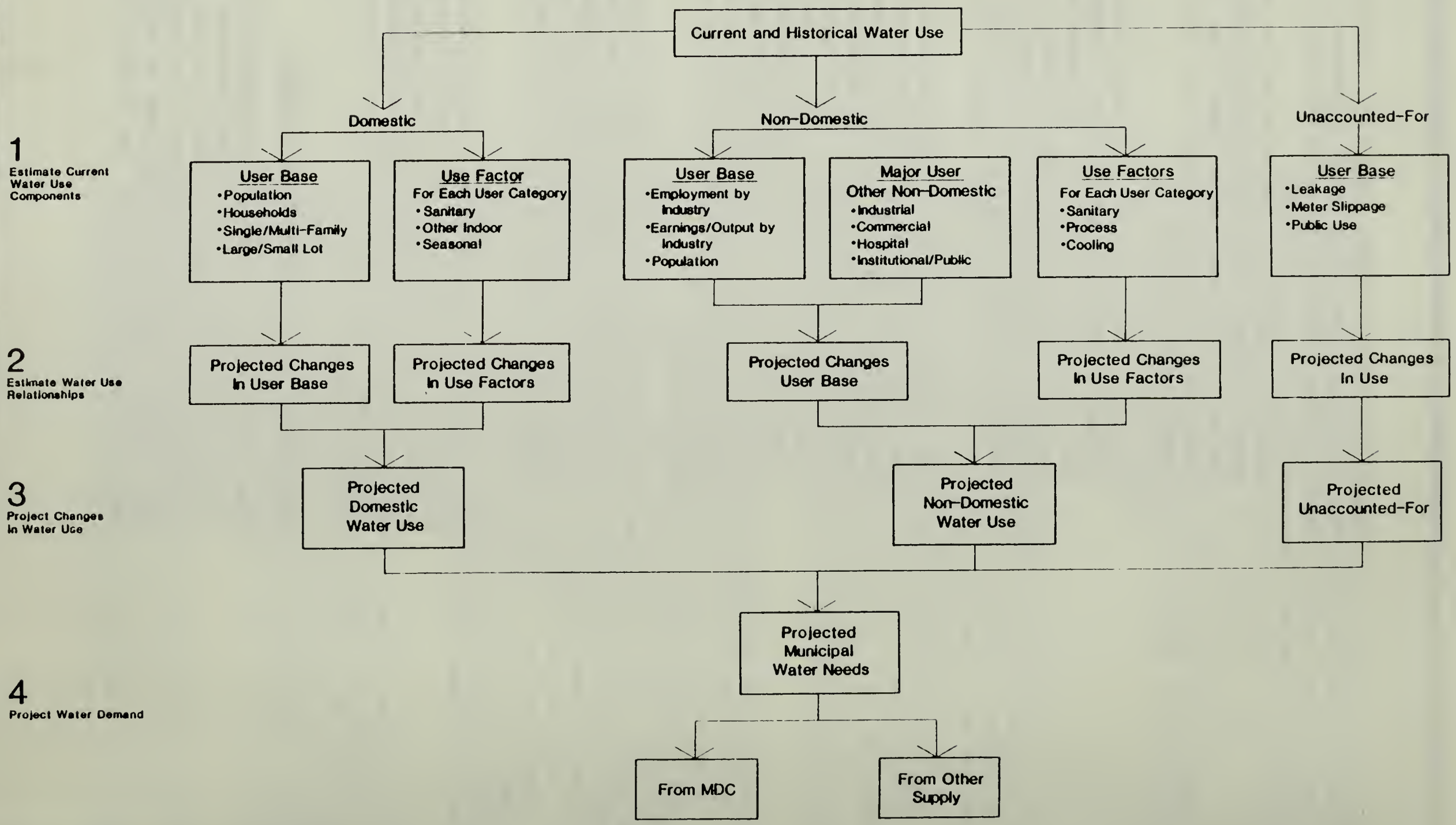
The structure of the model and the forecasts of the three principal water use components (metered domestic, metered nondomestic, and unaccounted-for) are based largely on two sets of factors: (1) demographic and economic growth factors, and (2) water use factors, as described in more detail below.

Demographic and Economic Growth Factors

These growth factors include the distribution and composition of the region's population, housing, and economic base in different communities over time and their relationship to different components and categories of water use. These projections are affected by national changes in demographic/economic factors, and by the relative

Figure 5.

Water Demand Simulation Model



attractiveness and growth of Massachusetts, the Boston metropolitan area, and individual communities.

There are a wide variety of forecasts available for these factors, and there is also considerable uncertainty surrounding 20- to 40-year forecasts. After an evaluation of a variety of models and forecasts, the Massachusetts Economic Policy Analysis Model (M.E.P.A.), developed by the University of Massachusetts at Amherst, was selected for use in this study to establish statewide forecasts. It was felt to be the best state-level approximation of the relationship between economic development and employment opportunities and population growth and migration. This model is subscribed to by other state agencies and incorporates both very current and long-term historical data.

The statewide "control" forecasts of population and employment (the middle of three M.E.P.A. forecasts) which have been used for the base water demand estimates generally fall in between most other forecasts (e.g., above the recent Metropolitan Area Planning Council (MAPC) forecasts and below the Office of State Planning (OSP) forecasts developed for Statewide §208 wastewater planning studies). These forecasts were allocated to individual communities based on recent community-level population and housing forecasts and on recent industrial development and employment growth rates.

Water Use Factors

These factors represent water use practices and efficiencies associated with different components and categories of water use and are measured on a per capita, per household, per employee, per visitor, or per unit of output basis. The factors are affected by plumbing codes, appliance standards, pretreatment or discharge requirements, and changing technologies, and by the rate of replacement or investment in different types of equipment over time. In order to forecast changes in water use factors over time, the estimates assumed no changes in current technology and assumed rates of adoption of existing technology based on surveys of major users, on existing plumbing codes and emerging appliance standards and treatment requirements, and on normal rates of replacement and useful lives of plumbing fixtures, appliances, and other water using equipment.

Current management practices or improvements, planned and funded, were assumed for projections of unaccounted-for water. For example:

- Meter replacement adjustments were made on the basis of accelerated meter replacement programs assumed to take place in a number of towns. These adjustments shifted use from unaccounted-for to metered use categories.

- Leakage recovery adjustments were made on the basis of the assumed use and effectiveness of leakage detection and repair programs (e.g., Chapter 805 grants). These adjustments resulted in reductions to unaccounted-for use forecasts.

Adjustments to Total Base Water Demand

In order to forecast base demand on the MDC, there were several adjustments which the model incorporated into its estimates:

- Special use adjustments included water use adjustments for individual users who get their water directly from the MDC, as well as for system use by the MDC. Forecasts of water use by individual users were based on past trends and user interviews; system use was based on MDC analysis of past trends.

- The availability and use of local water supplies encompasses the use of private supplies by individual users, the use of municipally-owned supplies, and inter-town transfers of water. These are affected by local safe yields, contamination and water quality requirements, costs, contractual agreements, and legal requirements.

- Lynn became an MDC member in January 1983, with a contract maximum of 4 MGD. Its future use was forecast to be its estimated future deficit (the MDC's existing supples to General Electric were forecast as part of the current users).

- Drought contingency included increased water use during drought and reduced use of local supplies. These adjustments were based on analysis of experience during the mid-1960s drought, and on individual dry years since then.

THREE MAJOR COMPONENTS OF WATER USE: METERED DOMESTIC, METERED NONDOMESTIC, AND UNACCOUNTED-FOR USE

METERED DOMESTIC WATER USE

Description of Domestic Use. Metered domestic use is defined as the metered residential use of water, excluding

nursing homes, colleges, hospitals, prisons, and other institutions. This use amounted to an estimated 143 MGD for the 44 MDC communities in 1980, as seen in Figure 6, "Total Water Use in the MDC Area 1980", and was 38 percent of total water used by these communities.

About 12 percent of the domestic use was estimated to be outdoor seasonal use, 66 percent was bathroom-related (primarily bathing and toilet flushing), and the remaining 22 percent was kitchen- and laundry-related (see Figure 7).

The relative importance of each of these components varied considerably from house to house. Large-lot suburban homes used 3 to 4 times the amount of water used by smaller apartments because of larger households, more water-using appliances, and a higher proportion of outdoor use. The relative importance of domestic use also varied considerably from community to community.

Modeling of Domestic Water Use. Four analyses were used in developing the model equations for forecasting domestic water use: (1) a statistical analysis of past water use in Massachusetts, both across communities and over time; (2) case studies of communities and different types of housing units; (3) other studies and analyses available in the literature; and (4) an assessment of changing water-using technologies, regulations, and practices.

The best explanatory equations for estimating reported 1980 domestic use in the 44 MDC communities were found to be:

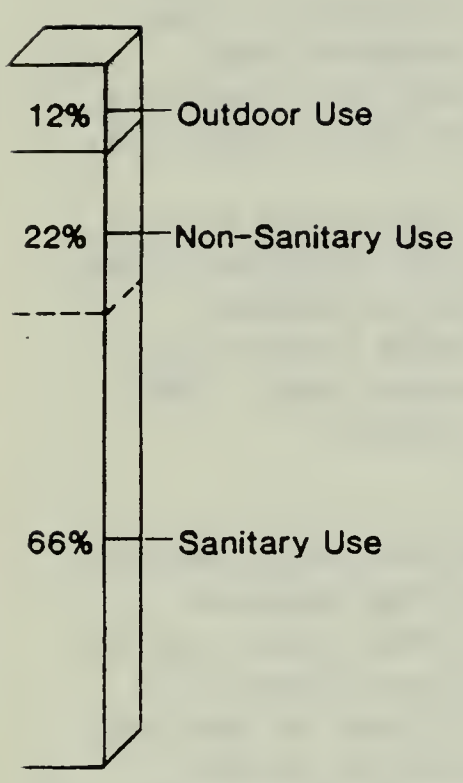
- 1980 nonseasonal domestic use = 55 gal/day/capita + 10 gal/day/multi-family household + 20 gal/day/single family household + unexplained reported use. (The single-family household water use factor was estimated at 40 gal/day in high-income communities and 15 gal/day in low-income communities.)

- 1980 seasonal domestic use = 2 gal/day/capita + 4 gal/day/multi-family household + 15 gal/day/single family household + unexplained reported use. (The single-family household water use factor was estimated at 30 gal/day in high-income communities and 7.5 gal/day in low-income communities.)

For most MDC communities, these equations resulted in a difference of less than 15 percent between domestic use estimated by the model and that reported to the MDC for 1980. In a third of the communities, representing 65 percent of MDC domestic use, the difference was less than 9 percent. Because there was no way to identify the causes of such differences, they were called unexplained domestic use, and forecast as a function of total domestic use.

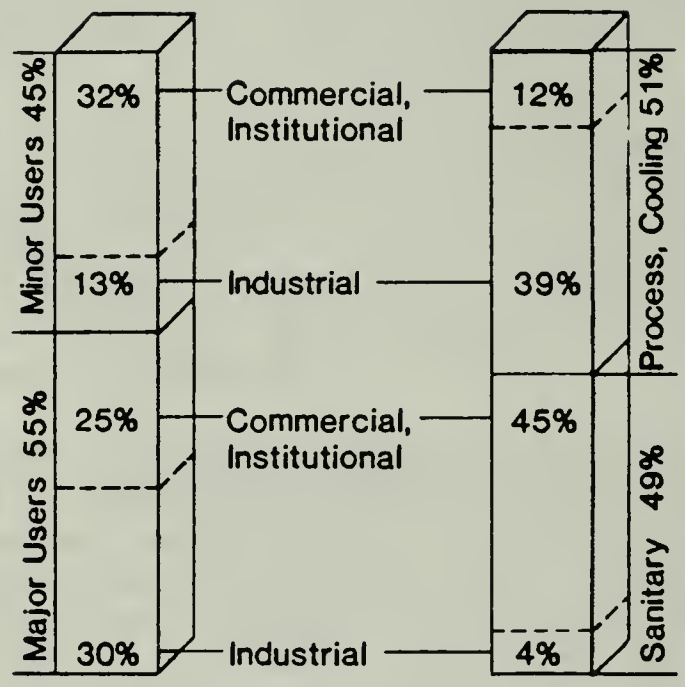
Figure 6.

Total Water Use in the MDC Area - 1980



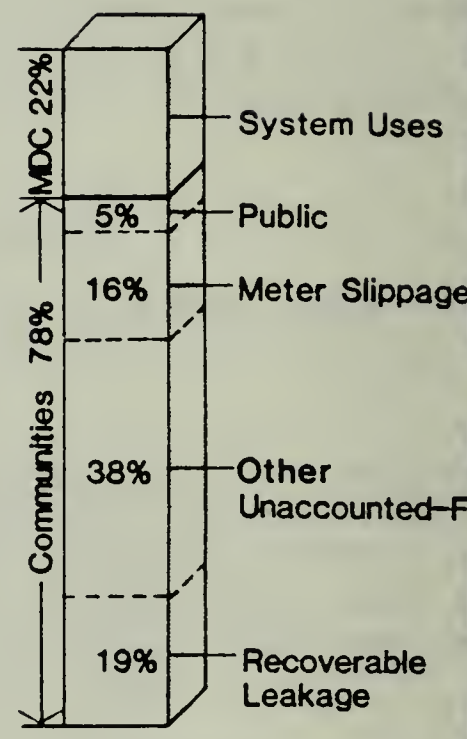
MGD

nestic



126.1 MGD

Non-Domestic

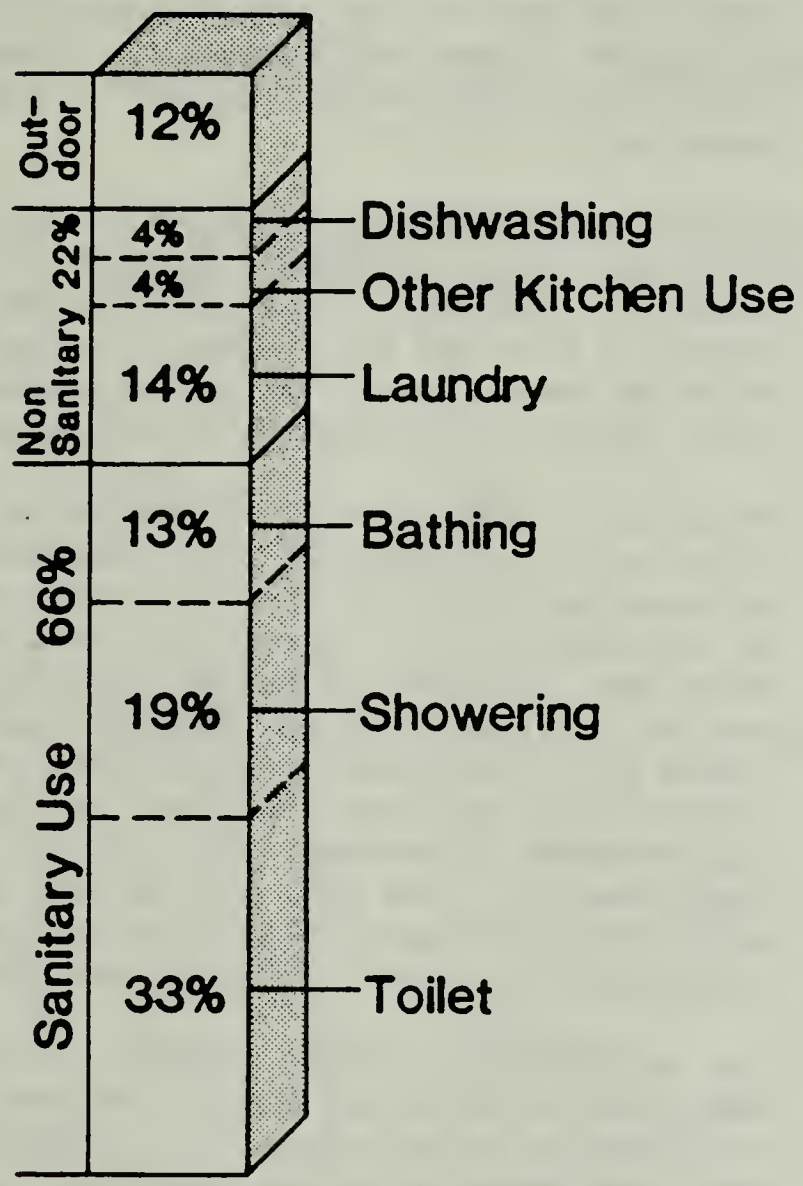


136.0 MGD

Unaccounted-For

Figure 7.

Domestic Water Use, 1980



These base year estimates of domestic water use relationships were used to forecast future domestic water use, as a function of the changes in population and housing units in each community and as a function of changes in water-using technologies and use practices. The demand simulation model demonstrated the water use implications of a changing population and housing stock composition, combined with the effects of normal replacement or altered use of various fixtures and appliances, as well as specific water conservation efforts.

Population and Housing Forecasts. To forecast domestic water use, it is necessary to have--for each community--forecasts of noninstitutional population, household size and the number of households, new and existing housing units by type (single-family versus multi-family), and average relative income level.

There are a wide variety of forecasts available for these indicators, and there is also considerable uncertainty surrounding long-term 20- to 40-year forecasts. The rate of reduction in U.S. fertility rates over the last 10 to 15 years has continued to exceed most forecasts, as has the rate of increase in U.S. life expectancy. Whether these trends will continue, or level off, or reverse themselves nationally is difficult to say; and cases can be made for a wide variety of perspectives both for the United States and Massachusetts. The same can be said for both U.S. immigration and particularly net migration to or from Massachusetts or the Boston metropolitan area.

The relationship between economic development and employment opportunities and population and household formation, is difficult to anticipate. As noted earlier, the M.E.P.A. model was selected as representing the best approximation of this dynamic and the range of uncertainties involved in forecasting the economic and demographic performance of Massachusetts relative to the rest of the country (See Table 6).

- At the national level, the M.E.P.A. model assumes the mid-level Census Series II forecasts which predict a U.S. population growth of 30 percent between 1980 and 2020.

- At the state level, the M.E.P.A. control forecasts to 2007 were used for the base demand estimates and extrapolated to 2020 (based on 2000-2007 rates of growth). The recommended statewide forecasts represent a Massachusetts growth rate substantially below (about 30 percent below) the U.S. Census Series II population growth forecast for the nation. This relative growth rate over the next 40 years is

ble 6. Population Forecasts, 1980 – 2020 (in thousands)

	1980	1990	2000	2007	2020	Cumulative % Change 1980-2020	Annual % Change 1980-2020
1. US Census Bureau Forecasts of US Population							
- Series II (Control)	222,480	243,520	260,900	270,470	289,200	30.0	0.66
2. M.E.P.A. Forecasts of Massachusetts Population							
- Control	5,740	6,137	6,418	6,573	6,869	19.7	0.45
3. M.E.P.A. Forecasts as Allocated to 44 Current MDC Communities							
- Control	2,178	2,278	2,353	-	2,439	12.0	0.28
4. M.E.P.A. Forecasts as Allocated to 36 Non MDC Communities in Planning Area							
- Control	742	808	883	-	999	34.6	0.75
Source: Arthur D. Little, Inc.							

generally consistent with the last 40 years of experience in Massachusetts.

- At the community level, the estimated population growth used for individual planning area communities was based on the relative community growth rates as allocated in the "Planning Area" report of this study. This was based on recent MAPC forecasts averaged with OSP forecasts used for the §208 wastewater planning studies. These community-level forecasts also incorporated information about the existing housing stock, zoning, community attractiveness, and residential development potentials in each community.

Household forecasts were derived community by community by having regional household size changes parallel national forecasts and by keeping relative household sizes at the community level constant. Housing unit forecasts were derived community by community by assuming constant vacancy rates and by having net new housing divided between single-family and multi-family units in the same proportion as represented by the building permit data for the past 10 years. Average relative incomes in each community were kept at their 1980 relationships.

Domestic Water Use Factor Forecasts. Domestic use factors for future years are adjustments to present water use factors based on newly adopted plumbing codes and appliance standards and related rates of replacement/rehabilitation and new construction. The estimated 1980 use factors were applied to 1972 demographic characteristics to estimate 1972 demand. The results indicate little change in use practices over the last eight years, and there appears to be no sound historical trend for forecasting changes in water use practices. Water use technologies and the efficiencies of fixtures and appliances are changing significantly though.

- For all net new housing units, no further changes in plumbing codes, appliance standards, or water-use efficiencies are assumed. However, it is assumed that new housing units will be in compliance with the new plumbing code. This will mean an estimated reduction in the per capita water use factors from 55 to 42.5 gal/cap/day due to code requirements for low-flow showerheads and water-saving toilets. Improved energy and water-use efficiencies of laundry and dish washing appliances are estimated to result in a 10 percent reduction in the nonseasonal household use factors.

- For the existing housing stock, it is estimated that 10 to 15 percent of all existing units will have been replaced or rehabilitated in terms of plumbing

fixtures and appliances by 1990 (20 to 30 percent by 2000 and 35 to 40 percent by 2020) with all fixtures and appliances meeting plumbing codes and standards as in new units. In addition, because showerheads have a useful life of about 15 years, it is estimated that 20 percent of all existing households will have replaced and/or retrofitted water-saving showerheads by 1990 (50 percent by 2000 and 90 percent by 2020) and that 50 percent of all households will have new washers and dishwashers by 1990 (90 percent by 2000). Based on interviews with plumbing suppliers, a useful life of 40 years for toilets is assumed. It is also assumed, conservatively, that the average age of current toilets is 15 to 20 years, and that due to breakage and obsolescence it was assumed that 25 percent of all existing households will replace their current toilet with water-saving models by 2000. Based on current experience, toilet dams and other toilet flush reduction devices were not expected to be installed voluntarily to any great degree. The result of these estimates for existing housing units is a reduction in the per capita water use factor from 55 gal/cap/day in 1980 to 52 gal/cap/day in 1990, 49 gal/cap/day in 2000, and 47 gal/cap/day in 2020, and an 8 percent reduction in the per-household nonseasonal water use factors by 2020. No changes are forecast in the outdoor seasonal use water use factors.

Domestic Water Use Summary and Forecast

Table 7 summarizes the components of metered domestic use, the estimated changes in population, housing, and water use factors and the base demand forecasts of domestic water use to 2020. Table 7 also summarizes the results of the sensitivity and probability assessments used to estimate the uncertainties associated with the water demand forecasts due to growth and water use factor estimates.

METERED NONDOMESTIC WATER USE

Description of Nondomestic Uses. Metered nondomestic use is defined as all metered nonresidential use of water, including institutions, industries, power plants, stores, offices, etc. This use amounted to an estimated 126 MGD for the MDC service area as shown in Figure 6, "Total Water Use in the MDC Area 1980". This amounted to 34 percent of total water used by the communities (including special users).

About 52 percent of this use in the MDC communities was represented by industrial users. Ninety percent of this industrial use was for process or cooling applications; the remainder was for sanitary uses. Some 48 percent of

able 7. Domestic Water Use Estimates & Forecasts

Domestic Water Use Component	1980 Metered Domestic Use (44 MDC Communities)	Estimated 1980 Use Factor	Estimated Change in Activities (1980-2020)	Estimated Change in Use Factors (1980-2020)
Outdoor seasonal use	17 MGD	2 gal/cap/day	population +12%	no change
		4 gal/m.f./day[1]	households +21%	no change
		15 gal/s.f./day[1]		no change
Bathroom use	82 MGD	55 gal/cap/day	population +12%	decline of about 15% for population living in existing units, 25% for population living in net new housing units[3]
Other indoor domestic use	44 MGD	10 gal/m.f./day[2]	households +21%	decline of about 8% in existing units, 10% in net new units[4]
		20 gal/s.f./day[2]		
TOTAL DOMESTIC USE	143 MGD			

	1980 Estimates		1990 Forecasts		2000 Forecasts		2020 Forecasts	
	44 MDC (MGD)	36 Non-MDC (MGD)	44 MDC (MGD)	36 Non-MDC (MGD)	44 MDC (MGD)	36 Non-MDC (MGD)	44 MDC (MGD)	36 Non-MDC (MGD)
Base domestic water use forecast (including meter replacement adjustments)	143.0	50.7	138.6	50.9	136.5	53.1	141.8	58.9
Additional domestic demand during extended droughts			2.5	2.0	2.5	2.0	2.5	2.0
Recommended ranges for incorporating[5] estimated uncertainties								
85% of uncertainties			±6	±2	±14	±5	±21	±9
90% of uncertainties			±10	±3	±18	±7	±26	±11
95% of uncertainties			±13	±4	±20	±8	±29	±12

[1] 30 gal/single family household/day for high-income communities, 7.5 gal/single-family household/day for low-income communities.

[2] 40 gal/single family household/day for high-income communities, 10 gal/single-family household/day for low-income communities.

[3] This assumes a 30% reduction in toilet flushing use where low flush toilets installed (50% replaced by 2020), and a 25% reduction in shower use where low flush showerheads are installed (90% replaced in 2020).

[4] This assumes that energy- and water-saving clothes washers save 20% of water used (75% replaced with these appliances by 2020) and that energy and water saving dishwashers save 15% of water used (75% replaced by those appliances by 2020).

[5] Use of a 95% certainty level in 1990, 90% in 2000, and 85% in 2020 was advised.

Source: Arthur D. Little, Inc.

nondomestic use was by commercial/institutional users whose use was 80 percent sanitary (related to employees, customers, and institutional residents) (See Figure 8).

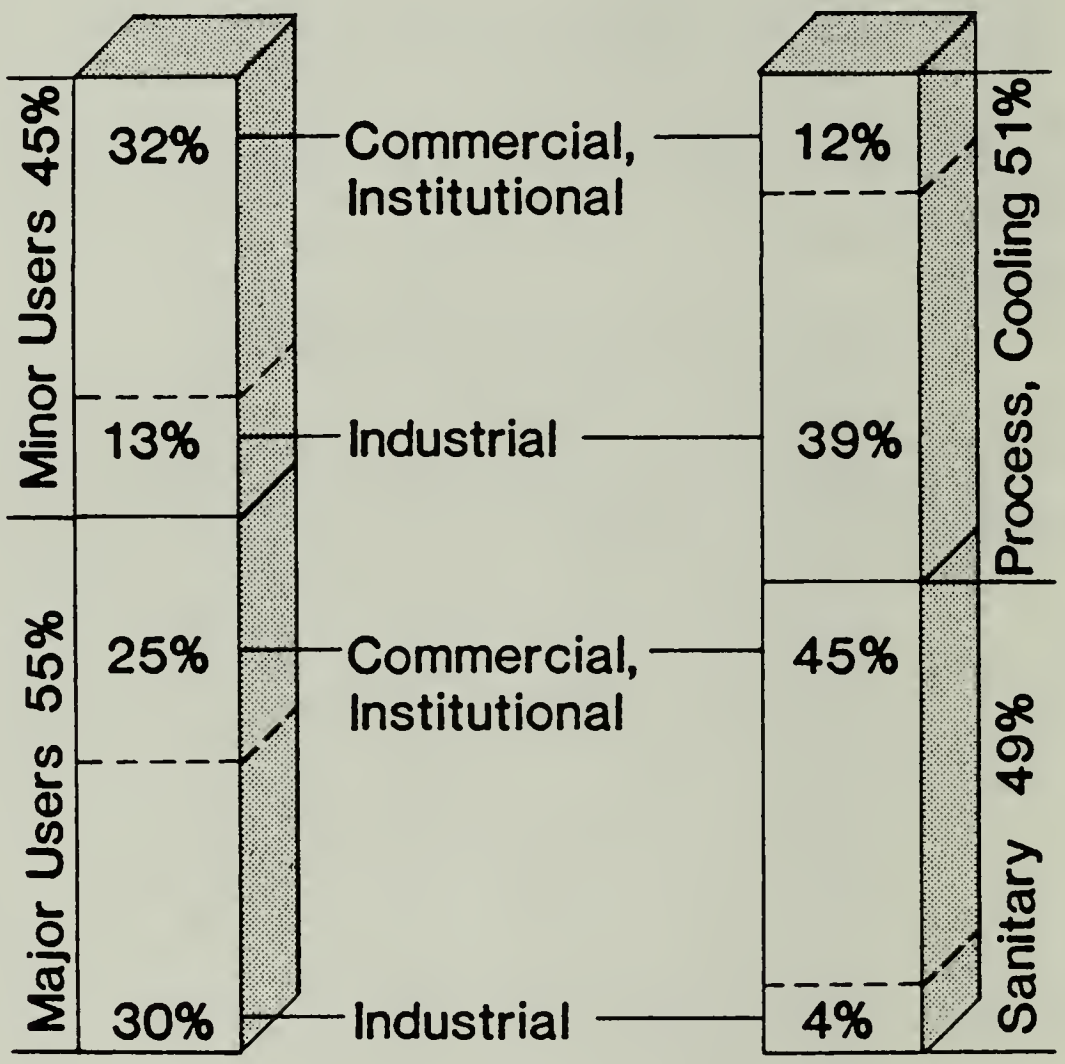
A large portion of nondomestic use was accounted for by 409 "major users" [users of more than 10 million gallons per year (MGY)]. These users accounted for about 55 percent of the nondomestic use. The 60 largest users accounted for 32 percent of total nondomestic use.

Types of water used varied considerably from industry to industry, as well as among nonindustrial activities. For example, nondurable goods manufacturers use more process water and much more water per employee than did durable goods manufacturers. The relative importance of nondomestic use varied considerably from community to community, ranging from 5 to 50 percent of total use.

Modeling of Nondomestic Water Use. Four analyses were used in developing the model equations for forecasting nondomestic water use: (1) an analysis of nondomestic water use and major users as reported in the MDC System Use (1975) (2) extensive interviews with major users of more than 10 MGD and analyses of accounts as provided by water departments and case studies of individual major users, (3) analyses of U.S. Census data on water use by manufacturers, and other studies available in the literature, and (4) an assessment of changing water use technologies, regulations and practices. Nondomestic water use in each community is allocated to (1) different major users (based on user surveys and water department data); (2) different categories of minor users (based on relative employment in the town and on the relative water intensity estimated for the region for each category of users); and (3) different types of water use (e.g., sanitary, process, cooling). These base year components of nondomestic water use for each community are then related to a weighted average of activity indicators (e.g., output, employment, institutional population), so that future estimates of nondomestic water use components are a function of altered technologies and use practices, and planned or potential conservation efforts, as estimated on the basis of the user interviews. The simulation model can demonstrate the water use implications of a changing economic structure in the region. The model incorporates explicit assumptions about the technology and efficiency of various water-using fixtures and appliances as they change over time and judgment about baseline changes in use practices and conservation.

Figure 8.

Nondomestic Water Use, 1980



Forecasts of Population, Employment, and Industrial Production.

In order to forecast nondomestic water use, it is necessary to have--for each community--forecasts of employment by industry and nonindustrial activity, forecasts of industrial production by industry, forecasts of institutional population, and forecasts of visitors and customers for various activities (using regional population forecasts as a surrogate).

As with population forecasts, there are a variety of forecasts available for these activities, and there is considerable uncertainty about 20- to 40-year forecasts, particularly given the recent structural shifts in the New England economy. Whether the traditional industries (e.g., food processing, textiles, apparel, chemicals) will continue to decline in New England or whether they have now stabilized is one important question, as is the question of continued growth in high-technology and service industries, including the strong performance of higher education institutions and hospitals.

The relationships between economic development, business costs, and employment opportunities and the characteristics of the region's population is complex. The mid-range control forecasts of the M.E.P.A. model were adopted for use in this study (See Table 8).

- At the national level, the M.E.P.A. model assumes the national employment and output forecasts of Data Resources, Inc. (DRI)--forecasts subscribed to by many federal agencies.

- At the state level, the employment forecasts under the mid-range control scenario for 2007 were used for the base demand forecasts, and extrapolated to 2020 (based on 2000-2007 rates of growth). These employment forecasts are generally higher than the U.S. Department of Commerce (OBERS) forecasts for the state, which were heavily influenced by the severe 1974-1975 recessionary impact on Massachusetts. The M.E.P.A. forecasts have employment growth occurring about two-thirds the national rate, a relative growth which is similar to Massachusetts' long-term historical performance but below its performance of the last seven years, when it has grown about the same rate as the United States.

- At the community level, the estimated allocation of statewide employment growth in individual industries to individual communities was based on the community's share of growth/decline in that industry over the last

Table 8. Employment Forecasts, 1980–2020 (in thousands)

	1980	1990	2000	2007	2020	Cumulative % Change 1980-2020	Annual % Change 1980-2020
1. Forecasts of U.S. Employment Based on U.S. Census Series II population as used in the M.E.P.A. model	90,530	105,230	116,640	124,980	142,000	56.9	1.13
2. M.E.P.A. Forecasts of Massachusetts Employment Based on U.S. Series II							
- Control Forecast	2,653	2,957	3,184	3,362	3,746	41.2	0.87
3. M.E.P.A. Employment Forecasts as Allocated to 44 Current MDC Communities							
- Control Forecast	1,257	1,427	1,532	-	1,817	44.6	0.93
4. M.E.P.A. Employment Forecasts as Allocated to 36 Non MDC Communities in the Planning Area							
- Control Forecast	313	372	412	-	487	55.6	1.11

Source: Arthur D. Little, Inc.

10 years, with no community having long-term growth in an industry at more than 150 percent of the statewide rate or less than 75 percent of this rate.

Industrial production estimates were derived for each industry and community from DRI's forecasts of changes in output per employee in each industry. Institutional population forecasts were developed as part of the population forecasts and were assumed to change at the same rate as regional population in all communities.

Nondomestic Water Use Factors Forecast. For individual major users and within individual industries, the data suggest that most major conservation measures and water use efficiency improvements have been made and that future water use will be primarily a function of future changes in employment activity indicators and the rate of replacement or new construction involving more water-efficient plumbing fixtures, appliances or water-using equipment (See Table 9)

- For sanitary use related to future employees or residents or customers, future water use factors are functions of the rate of retrofit and the addition of low-flow sanitary facilities. The sanitary use per employee is estimated to decline gradually from the average of 20 gallons per employee per day in 1980 to 17 in 2020, reflecting the increased use of industrial toilets with low flushometer settings, as now required by the plumbing code. The sanitary use per institutional resident is assumed to change in the aggregate by the same percentage as overall domestic use coefficients (a reduction of 13 percent by 2020). The use factor for customer-related sanitary use is assumed to change by the same percent as employee-related sanitary use (a decline of 15 percent).

- For industrial process use related to future output, future use factors for individual industries and major users are not expected to change, except due to specific changes in manufacturing processes and water-or energy-using technologies. Some of these have been identified in major user interviews. However, the rate of change of process use as a function of output is forecast to be dampened by 25 percent for "wet" industries (i.e., chemicals, food, paper) and 50 percent for all others.

- For industrial cooling use related to both output and space or facilities/equipment, altered future use factors are primarily a function of changing technologies (e.g., computer cooling) and their altered water use requirements. Additional

conservation and cost-reduction efforts (whether geared to energy conservation or water/waste treatment costs) are also important. Many changes in practices due to energy conservation (e.g., higher thermostat settings) were estimated to have been in place by 1980. The factors for cooling water use were assumed to be reduced by 10 percent by 2020 to account for further conservation based on major user interviews, case studies, and reviews of the literature. In order to relate facility, equipment, and space changes to changes in output and employment, it was estimated that these cooling needs would change at one-half the weighted rate of change in output/employment for each industry (with employment weighted at 0.25 and output at 0.75).

- For process/cooling use by commercial/institutional users related to space and facilities, water use factors were assumed to change by the same rate as industrial cooling (10 percent savings from conservation by 2020). Cooling-related needs are estimated to change at one-half the weighted rate of change in activity, as indicated by employment and resident/customer populations weighted equally.

Nondomestic Water Use Summary and Forecast

Table 9 summarizes the components of metered nondomestic use; the estimated changes in employment, output, institutional and regional population and water use factors; and the base demand forecasts for metered nondomestic water use to 2020. Table 9 also summarizes the results of the sensitivity and probability assessments used to estimate the uncertainties associated with the water demand forecasts due to growth and water use factor estimates.

UNACCOUNTED-FOR WATER USE

Introduction

Unaccounted-for water in user community distribution systems represents a significant portion of the water supplied by the MDC, on the order of 30 percent, as shown on Figure 6, "Total Water Use in the MDC Area 1980". It is calculated as the difference between the amount of water delivered by the MDC, as measured by the MDC revenue meters, and the community's reported metered use. Unaccounted-for water in local community systems is made up of several elements, including: water main leaks and breaks, meter inaccuracies, unmetered public use, unauthorized connections, and errors in estimates for

ble 9. Non-Domestic Water Use Estimates & Forecasts

ndomestic Water Use Component	1980 Nondomestic Use (44 MDC Communities)	Estimated 1980 Use Factor	Estimated Change in Activity 1980-2020	Estimated Change in Use Factors 1980-2020
nitary use	50.8	7,000 gal/yr/employee 32,850 gal/yr/institutional resident 8,000 gal/yr employee for other, but function of regional population	+45% +16% +16%	decline of approximately 10-15% due primarily to plumbing code requirements
ocess use	28.0	specific to each major user and each industry as function of output	varies by industry but averages even 200%	no change in use factors but changes dampened by 25-50% due to improved efficiencies and economies of scale
oling and scellaneous	39.7	specific to each major user and each industry as function of both output (75%) and employment (25%)	varies by industry but output growth averaged over 100% and employemnt about 8% in manufacturing and nonmanufacturing	10% reduction in use factor with additional dampening of 50% due to improved efficiencies and economies of scale
ecial Uses and ansfers	6.8	NA		
	126.1			

	1980 Estimates		1990 Forecasts		2000 Forecasts		2020 Forecasts	
	44 MDC (MGD)	36 Non-MDC (MGD)	44 MDC (MGD)	36 Non-MDC (MGD)	44 MDC (MGD)	36 Non-MDC (MGD)	44 MDC (MGD)	36 Non-MDC (MGD)
se non-domestic water e Forecast (including ter replacement justment)	126.1	19.4	136.9	21.3	14.49	23.7	164.9	29.7
commended ranges for corporating estimated certainties								
% of uncertainties							±26	
% of uncertainties					±25			
% of uncertainties			±11%					

urce: Arthur D. Little, Inc.

unmetered consumers; all of which are under the control o the user communities, not the MDC (See Figure 9).

The level of analysis is regional. While calculations we performed on an individual community basis, the confidenc in estimates of the elements of unaccounted-for water for single community is limited. The precision of estimates for groups of communities (e.g. fully-supplied MDC member is considerably higher. The estimates provided should provide a sound basis for MDC policy formulation.

MDC Revenue Meter Accuracy

Revenue meters measure the quantity of water delivered by the MDC to each community system. Approximately 161 revenue meters measure flow to the Metropolitan Water District Communities. There are two basic types: venturi, which are generally used to measure high volume flows, and compound, which are generally used to measure low volume flows.

Accuracy of revenue meters is critical, if accurate estimates of unaccounted-for water are to be provided. Inaccuracies in revenue meters are reflected, gallon-for-gallon, in unaccounted-for water, since unaccounted-for water is the difference between revenue meters and the sum of consumer meters.

The results of accuracy tests performed on many MDC revenu meters between 1976 and the present were reviewed. Based on this review, it was concluded that significant inaccuracies may exist. The data reviewed was not sufficient to assess whether the overall effect is over- o under-registration. The MDC is currently reconstructing 6 of its largest revenue meters. When data from these new meters becomes available in late 1983, a better assessment of the effect of revenue meter inaccuracy on unaccounted-for water will be possible. For purposes of this study, it is assumed that the revenue meters in the aggregate are accurate, and are not a factor in unaccounted-for water. Efforts should be made to verify this assumption as soon as data from the new meters become available.

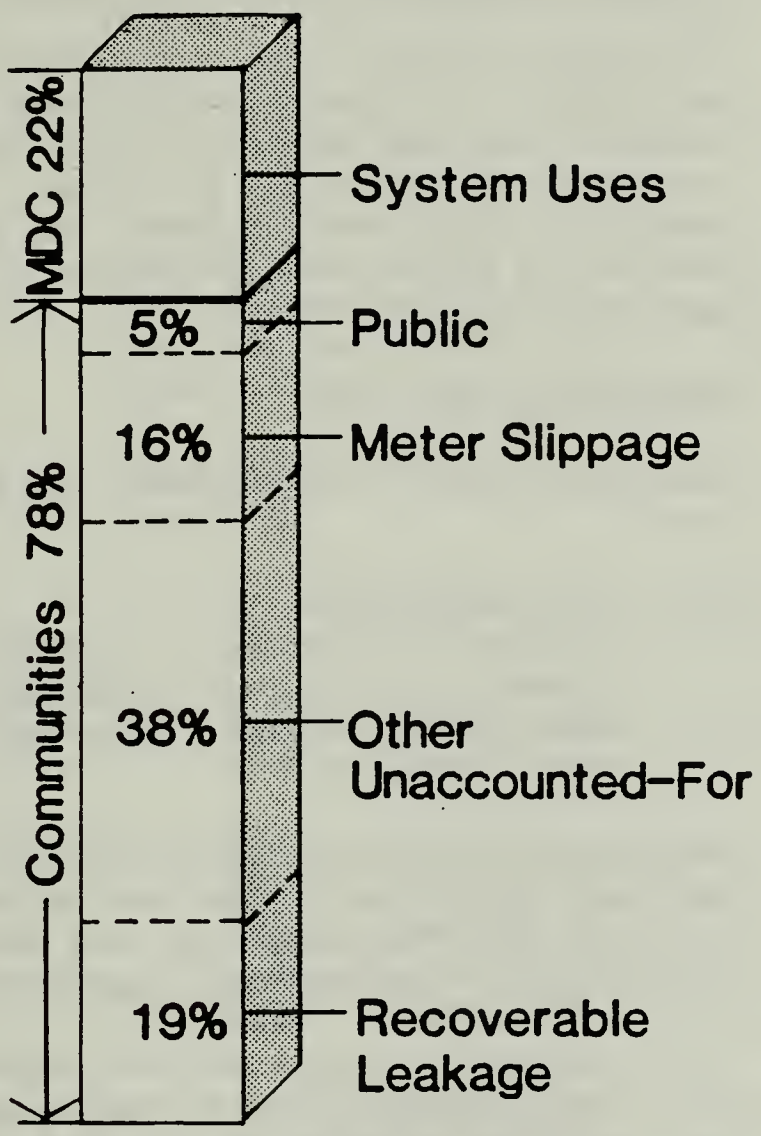
Domestic Meter Underregistration

Domestic meters are defined as those one inch or less in size. Underregistration is defined as the amount of water that passes through a meter and not recorded.

To assess the significance of domestic meter underregistration, a meter sampling and testing program wa undertaken with the cooperation of a number of

Figure 9.

Unaccounted-For Water Use, 1980



currently-supplied MDC communities. Over 400 meters were removed from service and tested for accuracy at three rates of flow. The results of the program suggest that domestic meter underregistration for planning area communities is between five and six percent of total domestic flow.

Nondomestic Meter Underregistration

Nondomestic meter underregistration was assessed by reviewing test reports for as many previously conducted in-situ tests as possible. Data was collected from tests conducted in Boston and Worcester, and the experience of a number of other water systems was reviewed. These data formed the basis for an estimate of 10 percent non-domestic meter underregistration.

Unmetered Public Use

Unmetered public use includes the following types of water use:

- fire-fighting;
- hydrant use for sewer flushing, water main blowoffs, and street cleaning;
- unauthorized hydrant openings; and
- main breaks.

The general practice among waterworks officials is to estimate unmetered public use as one percent or less of total supply. The analysis was designed to test this hypothesis. The approach consisted of four major elements:

- review of interviews with water department superintendents in currently-supplied communities;
- further in-depth discussions with an MDC-supplied community that kept records of estimated amounts of water used in fire fighting;
- review of pertinent technical literature; and
- discussions and evaluation of data from other East Coast water utilities.

Most currently-supplied communities did not account for any unmetered public uses. Some communities made estimates and kept records of some unmetered public uses. Upon questioning, some planning area communities were willing to provide estimates of some unmetered public uses. However, the most comprehensive accounting of these uses was provided by the Manchester, New Hampshire Water Department. Data from these various sources were assembled and analyzed. It was concluded that one percent of total supply is a generally valid estimate of unmetered public use. The exception to this estimate is Boston, where high

fire use and unauthorized hydrant openings result in an estimate of three percent of total supply.

Unavoidable Leakage

Unavoidable leakage is composed of numerous leaks too small to detect. A frequently-cited expression for unavoidable leakage is 250 gallons per day per mile of main per inch diameter. This is a derivative of an expression dating to 1897 which estimated unavoidable leakage as 2,500 to 3,000 gallons per day per mile of main.

The objective of this study was to assess the validity of these expressions. A literature search was conducted.

Staff and committee members of the American Water Works Association (AWWA) were interviewed. Discussions were held with Pitometer Associates, a leading authority on leakage and unaccounted-for water. Also, data from the 1981 AWWA "Water Utility Operating Data Survey" were analyzed.

As a result of these investigations, several points were apparent:

- It is generally acknowledged that some level of system leakage is unavoidable.

- The previously-mentioned expressions for unavoidable leakage are in common use.

- Some water supply engineers stated that unavoidable leakage must be determined on a system-by-system basis. However, no individuals or utilities contacted had estimated a quantity of unavoidable leakage for their distribution systems.

- When the traditional expressions are applied to urban or suburban water systems, unavoidable leakage generally comprises five percent or less of total supply (examples: Boston - 2.3 percent, Everett - 1.9 percent, Malden - 4.5 percent). However, when traditional expressions are applied to water systems in less densely populated communities, unavoidable leakage often exceeds 10 percent, and in the case of one planning area community constituted 28.4 percent of total supply. In this particular community, and in several other planning area communities, unavoidable leakage, as calculated by traditional expressions, exceeded total unaccounted-for water (calculated by subtracting accounted-for water from the total supplied to the distribution system).

- It is thought that a rational expression for unavoidable leakage would depend not merely on the length and diameter of pipes, but also on pipe material, system pressure, soil porosity and soil corrosivity.

Customarily, unavoidable leakage has been used as one of the categories of water use which, when subtracted from total supply, arrives at the remainder, recoverable leakage. Because the traditional expressions for unavoidable leakage are less than adequate, a means to calculate recoverable leakage independently of unavoidable leakage was developed for use in this study.

Recoverable Leakage

As indicated, the customary way to estimate recoverable leakage has been to deduct all known and estimated uses of water from the total supplied to a distribution system. This method has been used in the past to provide estimates of potentially recoverable leakage in MDC communities (U. Mass Water Resources Research Center, 1975; Linsky, 1980).

Several planning area communities have conducted leak detection and repair programs in their entire distribution systems in recent years. These communities were identified, and using the traditional method, potentially recoverable leakage was calculated for each community. Concurrently, data were requested from the MDC relative to monthly supply in the 12 months before and after the leak detection and repair program. The decrease in water supplied by the MDC after leak repair was determined. These supply decreases were compared to the values of potentially recoverable leakage computed by the traditional method. Based on these data, a relationship was developed between potentially recoverable leakage as calculated and decrease in supply, as an actual measurement. This relationship allowed estimates of supply decreases that would result from leak detection and repair to be calculated once certain basic system information was known.

Other Unaccounted-for Water

Certain elements of unaccounted-for water are present in all water distribution systems. However, each water distribution system has unique characteristics which result in categories of unaccounted-for water which may not exist in other systems. These may include:

- illegally-tapped fire lines;
- reservoir evaporation and leakage;
- standpipe overflows;
- data processing errors;

- errors in estimates for stopped meters;
- failure to account for public use that may be metered but not billed; and,
- revenue meters which overregister.

Each of these categories may exist in one or more communities, and it is safe to assume that some of these categories occur in all communities. However, a detailed engineering evaluation of each community distribution system would be required to more definitively quantify these elements of unaccounted-for water. Since such detailed engineering evaluations were beyond the scope of this current work, it was necessary to establish a general category to accommodate these varied elements of unaccounted-for water. This is termed "Other Unaccounted-For Water".

Estimates of Unaccounted-for Water

Unaccounted-for water is shown in Table 10, "Summary of Unaccounted-For Water in Currently-Supplied and Potential Future User Communities for 1980".

Projections of Unaccounted-for Water

Unaccounted-for water in currently-supplied and potential user community distribution systems was projected for the years 1990, 2000 and 2020. The general premise underlying this set of analyses is that existing practices and conditions will continue essentially unchanged, except in cases where a program already in place can be expected to produce some alteration in existing conditions.

In 1981 and 1982, the Massachusetts Chapter 805 and 286 leak detection grant program provided grant funds in the first two years of the five-year program to about half of the fully supplied communities. It is assumed that before the program expires, that planning area communities representing approximately seventy-five percent of total MDC supply will have received grant funds. This program is expected to produce a decrease in leakage (and unaccounted-for water and total supply) of approximately 18 MGD between now and 1990. Between 1990 and 2020, a slight increase in leakage (4 MGD) will occur as new leaks form, which, after the grant program expires, will remain unrepaired. Several communities currently have aggressive meter replacement and repair programs in place. Meter accuracy in these communities is estimated as somewhat higher than the average. This accounts for a slight decrease in unaccounted-for water (3 MGD), but no change in total supply because water is still being used, although it is now accounted-for in metered use projections.

Table 10. Summary of Unaccounted-For Water, 1980

Element of Unaccounted-for Water	Current Users MGD	Current Users Percent of Total Supply	Potential Future Users MGD	Potential Future Users Percent of Total Supply
Domestic Meter Underregistration	8.4	2.3	3.0	3.2
Non-Domestic Meter Underregistration	13.4	3.6	2.5	2.6
Unmetered Public Use	6.4	1.7	0.9	1.0
Recoverable Leakage	25.6	6.9	5.0	5.3
Other Unaccounted-For Water (Including Unavoidable Leakage)	52.0	14.1	10.2	10.7
TOTAL	105.8	28.6	21.6	22.8

Table 11. Projection of Unaccounted-For Water, 2020

Component	1990 MDC	1990 Non-MDC	2000 MDC	2000 Non-MDC	2020 MDC	2020 Non-MDC
Domestic Meter Underregistration	7.3	2.8	7.2	3.0	7.5	3.3
Non-Domestic Meter Underregistration	12.7	2.6	13.5	2.9	15.5	3.6
Unmetered Public Use	6.5	1.0	6.5	1.0	7.0	1.2
Recoverable Leakage	9.9	1.8	11.8	3.1	20.0	5.8
Other Unaccounted-For Water	52.0	10.2	52.0	10.2	52.0	10.2
TOTALS (in MGD)	88.4	18.4	91.0	20.2	102.0	24.1

The components of Other Unaccounted-For Water are largely unquantifiable, and no attempt to project how these miscellaneous factors may change in future years is made; the category is held constant for the study period.

When the foregoing assumptions are applied to the water use projections, the projections of unaccounted-for water are as presented in Table 11, "Projection of Elements of Unaccounted-For Water - Existing System Management Practices".

MDC SYSTEM USES

Unaccounted-for water in the MDC system is defined as the difference between the water withdrawn from the supply sources and the water delivered to water user communities as measured by the MDC's revenue meters. The MDC has a number of "master" meters which measure the withdrawals from supply sources and other internal system transfers. The locations of key master meters are shown in Appendix F-1.

The components of MDC unaccounted-for water are primarily meter error, maintenance work and leakage. Other factors, such as reservoir evaporation and seepage, unauthorized use and unintentional waste (as in a reservoir overflow), also contribute. Meter error is being addressed by the MDC in its Meter System Modernization program. It is still too early to assess how much of a factor meter error may be until actual operating results of the program are available. Water use for MDC maintenance work has increased in recent years due to acceleration of MDC aqueduct relining and pipeline replacement programs. This work typically requires draining the facilities prior to the work, flushing to waste for both cleaning and disinfection after the work and, finally, refilling. Other maintenance work, such as meter testing and draining and cleaning of tanks or reservoirs, also requires water. MDC distribution system leakage includes both avoidable and unavoidable leakage. A leakage survey is currently underway through which MDC expects to reduce avoidable leakage. The actual reduction of unaccounted-for water resulting from this program will be available after the leaks are repaired, which is estimated to be in late 1983.

In 1980 two major unusual events influenced the level of unaccounted-for water. The first was the shutdown of the Dorchester Tunnel for repairs in early 1980. This required use of the Sudbury Aqueduct to supply the Chestnut Hill Pumping Station. The Sudbury Aqueduct in turn had to be supplied from Reservoir No. 3 in the Sudbury system. Both the Sudbury Aqueduct and the reservoirs in the MDC's Sudbury System are emergency reserves and are not normally

used. Therefore, Reservoir No. 3's poorer water quality necessitated a release of dilution water from Wachusett Reservoir to the Sudbury System. This was accomplished by sending additional water to Reservoir No. 3 via the Wachusett Aqueduct and also through a blow off valve on the Hultman Aqueduct. The amount put into the Sudbury System exceeded the amount withdrawn by approximately 1.6 MGD as an annual average for 1980.

The second unusual occurrence was the construction of a new pipeline across Spot Pond Reservoir in Stoneham, Massachusetts. Route studies for a new 48" discharge pipeline at the Spot Pond Pumping Station had shown the the most cost effective and least disruptive route was to dewater the reservoir and construct the pipeline across the reservoir bottom. Construction of this pipeline took place in the spring and early summer of 1980. Spot Pond reservoir was dewatered initially by drawing water back into the distribution system using the intakes. However, the lower portions of the 2 billion gallon reservoir were below the intakes and had to be pumped to waste via an outlet brook. This pumping was necessary due to the poorer water quality of the lower portions of the reservoir.

There was other maintenance-related water use in the MDC distribution system during 1980 for projects, such as the cleaning and relining of Weston Aqueduct and replacement of steel pipelines. However, these programs are ongoing and can be expected to be part of future water use. The calculation of the unaccounted-for water for 1980 is shown in Appendix F-2.

Although the 1980 MDC system usage was 30.1 MGD, the MDC has estimated that its future baseline system usage will be approximately 21 MGD. This reflects the reduction attributable to the special occurrences in 1980, as well as improved system efficiency resulting from current programs. As part of the leak detection program MDC anticipates a reduction of MDC system usage on the order of 2 - 5 MGD. This anticipated savings is incorporated in the demand management work.

Past practice for the MDC in reporting its demand has been only to report the demands of its users as measured by the MDC revenue meters. This has been somewhat misleading since the amount actually withdrawn from MDC supply sources has been greater than the reported demand by the amount of unaccounted-for water within the MDC system. This MDC system usage must be considered with the needs of MDC user communities in order to accurately define the amount needed to be furnished from the MDC supply sources. As such, the 21 MGD projected MDC system usage has been included as part of the baseline future water needs.

ASE WATER DEMAND
ORECASTS

The base forecast of annual water demand on the MDC by current users of the system is 328 MGD in 1990 and 369 MGD in 2020. The 2020 estimate represents a slight increase of about 7 percent from the 343 MGD actually supplied by the MDC in 1980.

Domestic Water Use is Estimated to be Relatively Stable Over the Forecast Period. This is the result of the offsetting effects of moderate increases in projected population and housing units and projections of moderate improvements in water-using efficiencies due to the new plumbing code and appliance standards.

Nondomestic Water Use is Estimated to Increase. Metered nondomestic water use is estimated to increase by 39 MGD or 31 percent for the 44 MDC communities by 2020. These increases are the result of substantial increases in employment and industrial output, moderated in part by the effects of modest improvements in water-use efficiencies and, in part, by the estimated shifts from more water-intensive manufacturing of nondurable goods to less water-intensive manufacturing of durable goods and service industries.

Unaccounted-For Water Use is Estimated to Decline Substantially. By 1990, unaccounted for water use is forecast to decline by 18 MGD or 17 percent for the 44 MDC communities. Much of the reductions are the result of recovery of distribution system leakage by communities anticipated over the next three years, an effort stimulated in part by state matching grants to communities authorized under Chapter 286. A small amount of the reduction is due to aggressive meter replacement programs which appropriately enables a shift of use from the unaccounted-for category to metered use. By 2020, unaccounted-for use would return to 97 percent of the 1980 use due to increases in metered demand and to recurrent leakage in communities other than Boston. This assumes no continuation of the aggressive leakage detection and repair programs except in Boston where plans are in place.

Special Uses are Forecast to Decline. The water use level of 30 MGD by the MDC in 1980 was abnormally high due primarily to the unusually high MDC system uses resulting from work on Spot Pond, and 21 MGD has been selected, as system use has been estimated to decline to 21 MGD in the future. Water use by General Electric in Lynn has also been forecast to decline as the result of planned conservation measures. Other special users are projected to maintain relatively constant water use.

Use of Local Supplies is Estimated to Be Relatively Stable. Demand on the MDC by partial users depends on the sufficiency of their local supplies and on contractual provisions between the MDC and the individual community. Because both the local supplies and contracts are community-specific, the amount of water which the community is expected to supply in the future was estimated separately for each community. Contractual provisions which may specify minimum or maximum withdrawal rates constrain the demand on MDC (except in the case of Marlborough, which is likely to require more than 4 MGD in the future). Where the safe yield of local supplies, as reported by the community water departments, reflects the average amount actually used, the demand on the MDC was considered to be the difference between total demand and reported safe yield. For towns which continue to provide from local supplies an amount significantly different from their reported safe yields, an average of use in recent years was used to determine future demand on the MDC. The estimates of local supplies of the partial users included in the demand projections are detailed in Table 12.

FORECASTS OF ADDITIONAL POTENTIAL DEMANDS ON MDC

Additional potential demands on the MDC which must be planned-for include additional legal obligations to current users and eligible communities (estimated to be approximately 53 MGD), the potential deficits of communities which could feasibly be served by MDC (estimated to be approximately 4 to 5 MGD), and the potential needs that could arise on a short- or long-term basis due to contamination of local water supplies in communities that could be feasibly served by MDC (estimated to be approximately 11 MGD in 1990 and increasing to about 28 MGD in 2020). Communities included in the additional potential demand are shown in Figure 10.

ADDITIONAL LEGAL OBLIGATIONS OF THE MDC

The MDC has a variety of additional legal obligations to its current partially-supplied members and nonmembers contract users, as well as to communities legally entitled or eligible to receive water from the MDC.

Eight MDC-member towns (Cambridge, Canton, Needham, Peabody, Wakefield, Wellesley, Winchester, and Woburn) are currently partially-supplied. The MDC is legally obligated, under their rights as members of the MDC Water District, to fully supply these members upon request. Providing the full supply of water to these members would increase demand by 37 MGD in 2020. (A ninth town, Weston, is a member under a partial-supply agreement; but it receives all of its water from the MDC.) Lynn became a ne

e 12. Use of MDC Water by Partial Users (MGD)

	MDC Supplies		Local Supplies			MDC Contractual Constraints		Amount of Local Supplies Used in Demand Projections
	1980	5-year Average[1]	1980	5-year Average[1]	Reported SY	MIN	MAX	
ers								
bridge	0.07	0.03	17.12	18.07[2]	17.60	None	None[6]	17.6[13]
ton	1.45	1.31	1.58	1.67	3.60	1/3	3.0[7]	1.6[14]
dham	1.08	1.05	2.55	2.41	2.50	30%	None[8]	2.5[13]
body	2.32	1.57	6.14	5.78	4.17	None	None[8]	5.8[14]
efield	1.64	1.93	0.79	0.66[3]	0.66	1/3	None[8]	0.66[13]
lesley	0	0	3.05	3.04[3]	5.20	None	7.5[9]	5.20[13]
ton	1.14	1.12[4]	0	0	0	1/3	None[10]	0
chester	NA	1.27[5]	NA	1.23[4]	0.70	1/3	None	0.70[13]
urn	1.05	0.92	5.65	5.56	4.50	1/3	13.0	4.50[13]
embers								
mingham	8.40	8.12	0.21	0.27	2.50	None	17.15[11]	0.25[14]
minster	1.34	0.98	4.83	n.a.	7.40	1.0	5.0	12.4[15]
lborough	3.77	3.38	0.35	0.59	1.50	None	4.0[12]	0.60[14]
thborough	0.07	0.03	0.62	0.62[3]	0.90	None	None[9]	0.62[13]
cester	0	0.13	25.67	26.35[3]	29.00	None	10.0	29.00[13]

---

[1] 77-81
[2] mbridge used more than 19.73 in 1967-75.
[3] 76-80.
[4] cludes 1980 (1976-79 and 1981).
[5] year average. No use prior to 1979.
[6] less there results a pressure problem for the MDC system.
[7] ntractual maximum equals 12.5.
[8] 1 mgd, at MDC discretion.
[9] None, at MDC discretion.
[10] Limitations apply when town reservoir is more than half full.
[11] 10 mgd, if Millers River diversion is constructed.
[12] Unless MDC is repairing Wachusett.
[13] Reported safe yield.
[14] Average use in recent years.
[15] Reported safe yield excluding MDC supplies.

where local sy #s differed year to year causing fluctuations in takings from MDC, average of 5 year local sy was used. 1/(5...)

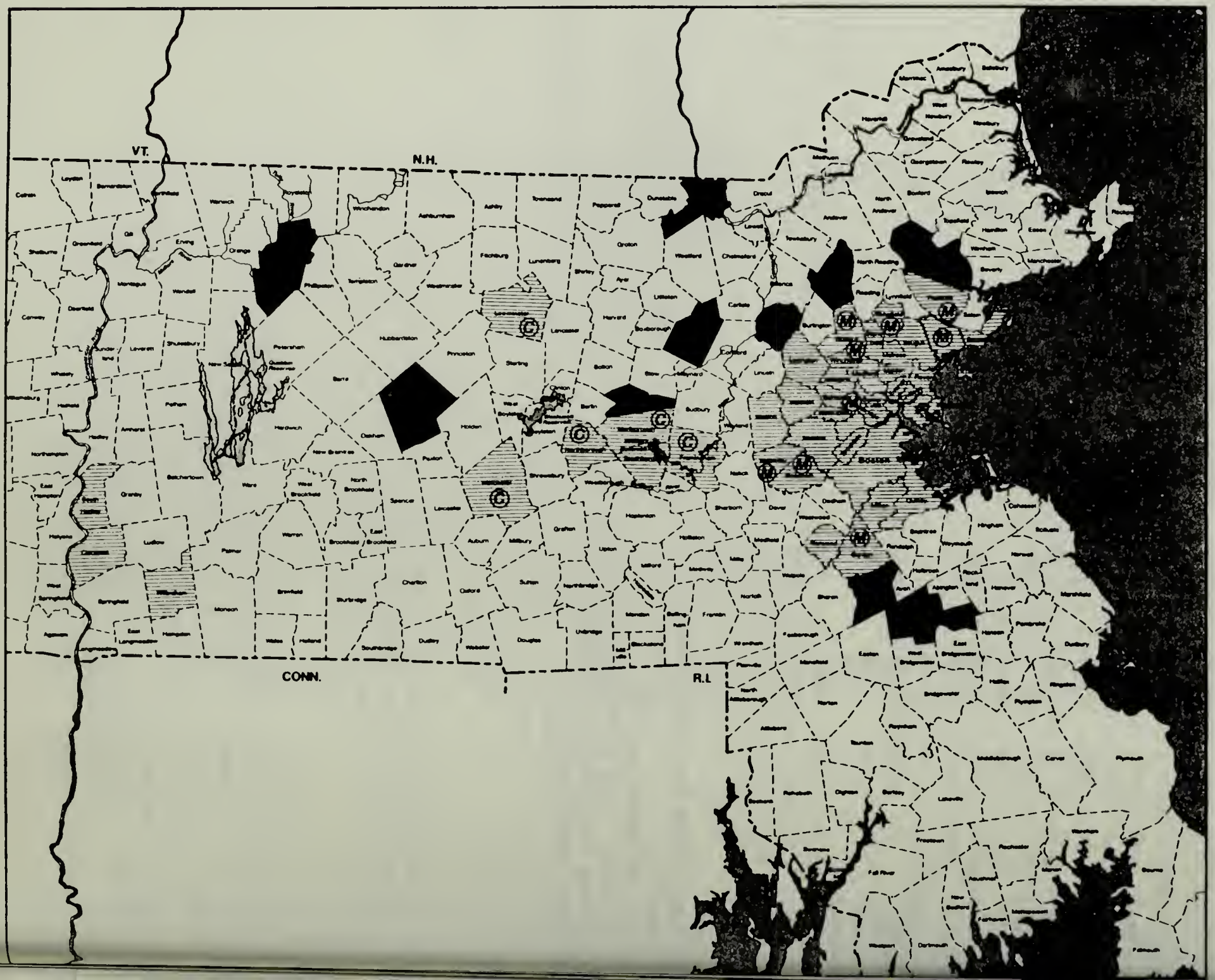


Figure 10.
Potential Additional Demand on the MDC

Legend

- Current Users
- Potential Future Users Projected to Face Deficits

Included in Additional Legal Obligation

- (M) Member – Partially Supplied
- (C) Contract User – Partially Supplied
- (E) Eligible Community Projected to Face Deficit

0 5 10 Miles

MDC Water Supply Study and EIR 2020 Phase II

Metropolitan District Commission

Wallace, Floyd Associates, Inc.
Architects/Planners

member in 1983, but the MDC's contractual obligation to Lynn is limited to 4 MGD.

Five towns (Framingham, Leominster, Marlborough, Northborough, and Worcester) are not members of the district but are partially-supplied under contracts with the MDC. If these towns were to purchase the maximum amount (not contract maximum, but maximum or demand, whichever is less), they would increase demand by 15 MGD in 2020.

Massachusetts General Laws, Chapter 92, §10(1), states that any community any part of which is within a 15-mile radius of the State House (but outside the 10-mile radius) is eligible to membership in the Metropolitan Water District, if it can be reasonably supplied. In light of recent amendments to §10(7) which require communities to maintain their local supplies to the extent feasible, as stated in C.382 Section 1 of the Statutes 1981, the additional obligation of the MDC to the eligible communities is assumed to be limited to the projected difference between their demand and their local safe yield. The projected deficits faced by Bedford, Danvers/Middleton, and Stoughton, which are eligible communities, are estimated at less than 2 MGD in 2020. Table 13 summarizes the legal obligations of the MDC to each group of communities.

In using these estimates of additional legal obligations to arrive at a capacity planning estimate, they must be reduced by 2.5 MGD to reflect the reduced use of local supplies already accounted for under the drought contingency in the base demand estimate.

ADDITIONAL POTENTIAL DEMAND ON MDC TO MEET SUPPLY DEFICITS OF COMMUNITIES

The planning area included additional communities that may face water deficits in the future and are located so that supply by the MDC might be feasible. Of these 36 communities analyzed, 7 are projected to face deficits which amount to 5.2 MGD in 2020. Deficits in Brockton, Whitman, and Tyngsborough (currently without a local water system) constitute most of this additional potential demand in 2020.

ADDITIONAL POTENTIAL DEMAND ON MDC TO MEET SUPPLY DEFICITS ARISING OUT OF LOCAL SUPPLY CONTAMINATION

Increasingly, local water supplies have experienced incidents of contamination through which communities have lost either a portion or all of their water supply. After reviewing the incidents of contamination that have occurred over the past three years (1978-1980) reported by the

Table 13. Additional Legal Obligations of the MDC (MGD)

Reflects obligations beyond base demand projection - sy but not exceeding any water demand deficit projections. Base demand for partials reflects past 5 yrs of takings as regardless (local sy) history of water takings pattern - if sy used first this was subtracted) See Table 12.

Additional Legal Obligations:

	1990	2000	2020
Current users			
- Partially supplied members[1]	35.48	36.09	36.67
- Cambridge	16.71	17.26	17.60
- Canton	1.60	1.60	1.60
- Needham	2.50	2.50	2.50
- Peabody	5.80	5.80	5.80
- Wakefield	0.66	0.66	0.66
- Wellesley	3.01	3.07	3.31
- Winchester	0.70	0.70	0.70
- Woburn	4.50	4.50	4.50
- Partially supplied nonmembers			
- Framingham[1]	0.25	0.25	0.25
- Leominster[2]	4.00	4.00	4.00
- Marlborough[3]	0.00	0.00	0.00
- Northborough[1]	0.62	0.62	0.62
- Worcester[2]	10.00	10.00	10.00
Lynn	2.36	1.88	0
Potential future users[4]			
- Eligible (deficits)	0.51	0.71	1.72
- Bedford	0.00	0.00	0.14
- Danvers/Middleton	0.00	0.07	0.69
- Stoughton	0.51	0.64	0.89
TOTAL	53.22	53.55	53.26

$\frac{-2.5}{50.7}$ Drought Addition which is in base

[1]Additional legal obligations represent excess of demand over projected base demand on the MDC--or the amount expected to be supplied from local sources.

[2]Additional legal obligations represent contractual maximum, less projected base demand on the MDC.

[3]Projected demand exceeds sum of estimated local supply and MDC contractual maximum. It is assumed that MDC would supply the forecast deficit as part of the base demand.

[4]Additional legal obligations represent excess of forecast demand over reported safe yield.

Special Legislative Commission on Water Supply in communities within the MDC planning area, over 10 MGD of local water supply were involved in contamination episodes. This represents approximately five percent of the total local water supply sources within the planning area in 1980. In two cases the sources have been recovered, so that only 9 MGD have been lost in the long-term, which is 4.3 percent of the total local water supply. Over two-thirds of these contamination incidents occurred in communities that are current or entitled users of the MDC.

While many of the contamination incidents resulted from disposal practices of several decades ago, improved testing techniques and greater awareness of potential sources of contamination has resulted in an increased rate of uncovering contamination events. This acceleration in testing and reporting of contaminations may mean an increase in reported contamination problems. Although efforts have been under way for several years to reduce the amount of salt used for snow removal, many communities still report problems with increasing sodium levels in their water supplies. Iron and manganese is a persistent water quality problem throughout the metropolitan area due to the geologic history, and communities report this to be an increasing problem with their local groundwater supplies.

Because contaminated local supplies could result in demand for water from the MDC, the capacity planning estimate includes an estimate for the possible loss of local supply due to contamination. While it is difficult to predict how this contamination will occur over time, if the recent experience were to continue over the planning period, approximately 55 percent of local water sources would be affected by contamination. This would mean 115 MGD would be lost effectively as local supplies. Present efforts to protect groundwater sources may reduce this trend; however past data indicate that contamination most frequently occurs in more urbanized areas, and that the percentage of supply affected may increase over the planning period. For these reasons, separate contamination factors were developed for those entitled communities within a 10-mile radius and communities in the rest of the planning area. For entitled communities, factors of 10, 15, and 20 percent were used over time as percentage of local supply lost, while for other communities in the planning area, 5, 8, and 10 percent were used. These estimates are detailed in Table 14. All towns which are entitled or eligible for MDC membership, or which could be feasibly connected to MDC supplies have been included in the contamination contingency calculation. Those included in legal obligations have not been included here.

able 14. Potential Additional Demands on the MDC Due to Contamination of Local Supplies (MGD)

ontamination Contingency:	1990	2000	2020
Local supplies used by entitled current users	35.48	36.09	36.67
Less: local supplies included in base demand (additional legal obligations)	(35.48)	(36.09)	(36.67)
Local supplies used by entitled potential future users (Lynn & Dedham/Westwood)	16.82	17.93	22.75
Less: local supplies included in base demand (additional legal obligations to Lynn)	(2.36)	(1.88)	0
Local supplies used by other entitled users (Weymouth)	4.77	5.18	5.94
Total, net local supplies used by entitled users	19.23	21.23	28.69
Contamination factor	10%	15%	20%
Contamination contingency for entitled users	1.92	3.18	5.74
Local supplies used by other current users	26.86	28.11	31.93
Less: local supplies included in base demand (additional legal obligations)	(14.87)	(14.87)	(14.87)
Local supplies used by other potential future users	69.56	73.75	80.19
Local supplies used by other towns with feasible MDC connection or eligible for MDC membership	95.28	106.50	126.04
Total, net local supplies used by eligible and feasible users	176.83	193.49	223.29
Contamination factor	5%	8%	10%
Contamination contingency for eligible and feasible users	8.84	15.48	22.33
TOTAL	10.76	18.66	28.07

UNCERTAINTIES IN THE WATER USE FORECASTS

Massachusetts and the Boston Metropolitan area are now going through a well-documented and dramatic change in their underlying economic structure which makes for considerable uncertainty in forecasts of employment, population, and industrial output. In addition, major cost shifts in water/sewer treatment, energy, etc., combined with improvements in technology and recent changes in plumbing codes and appliance standards are substantially affecting the way people and industries use water.

There are significant uncertainties associated with each of these factors and their effects on water needs over even a 10-year period, let alone a 40-year period. Consequently, the confidence level associated with an estimate of potential demands on the MDC is dependent on the estimated joint probabilities of uncertainties associated with all of these factors. As the time period gets longer, a wider range must be used to maintain the same confidence level. Alternatively, as the time period gets longer, greater uncertainties are tolerated. For estimating capacity planning ranges, a 95 percent certainty for 1990, 90 percent for 2000, and 85 percent for 2020 were used. Sensitivity analyses were used to develop reasonable bounds and confidence levels for water needs estimates associated with each of these uncertainties. The capacity planning estimate incorporated the most likely range of future water use in the light of uncertainties regarding both population/economic growth and water use factors. The approach to establishing these bounds consisted of four steps:

1) The uncertainties of individual assumptions or estimates associated with water use factors and associated with growth forecasts were assessed, as was the likelihood of these alternative assumptions.

2) The combined impact of alternative assumptions of water use factors on water use was subjected to a sensitivity analysis, and this assessment included the impact of regional and national growth factors on water use.

3) A joint probability matrix (for 1990, 2000, 2020) of the likelihood of alternative base demand forecasts was constructed for domestic and nondomestic water use associated with different ranges of growth and use factor estimates.

4) Confidence estimates of water use forecast ranges and their associated probabilities were developed, based

on the calculations for individual categories developed in Step 3.

Growth and Use Factor Uncertainties

The principal uncertainties incorporated in this assessment are:

- Growth Forecast Uncertainties. There are significant uncertainties about long-term U.S. population growth. The U.S. Census Bureau's forecasts, reflect a range of between 16 and 61 percent by 2020. Significant uncertainties also exist regarding the relative growth rates for Massachusetts and the Boston Metropolitan area in relation to the nation as a whole since they have ranged from 30 to 80 percent over the last 40 years. A probability of 60 percent that future 2020 population and households would fall within ±6 percent of the M.E.P.A. control forecast used for the baseline was estimated. A probability of 85 percent that future 2020 population would fall within ±10 percent, and a probability that all possibilities would be covered within a range of ±20 percent, were also assumed. Parallel estimates for forecasts of employment and industrial output were also developed.

- Use Factor Uncertainties. The major uncertainties with the use factors were considered to be the rate of compliance with the new plumbing code standards and emerging appliance standards, the rate of adoption of improved cooling systems and process use technologies by industry, and the extent to which improved appliance and process technologies are more water-efficient. Since there are a wide variety of fixtures, appliances, systems, and technologies involved, the potential of both slower and faster rates of adoption in each area was assessed individually.

Sensitivity Analysis and Probability Estimates

Three calculations of impacts were used in the sensitivity analyses:

- Impacts of Growth Forecast Uncertainties. The population and housing growth uncertainties proportionately affected the domestic use and the portions of nondomestic use covering institutional residents and customer-related sanitary use. The employment growth uncertainties proportionately affected the employee-related sanitary use and indirectly affected a small portion of the cooling use, while the industrial output growth uncertainties

affected, but not proportionately, the process use and part of the cooling use.

- Impact of Use Factor Uncertainties. The mixture of use factor uncertainties was estimated to impact domestic use in such a way that a probability of 65 percent for impacts of ±6 percent, and 85 percent for impacts of ±20 percent was assumed; and all potential impacts were included in a range of ±20 percent. For nondomestic sanitary use, because of its greater sensitivity to plumbing code assumptions, the estimated probability of ±6 percent was reduced to 45 and 75 percent for ±10 percent, with the total range remaining at ±20 percent. For nondomestic process/cooling use, the assessments were more complicated, but the estimated range of impacts of ±10 percent was still felt to incorporate a probability of about 75 percent.

- Combined Impact of Growth and Use Factor Uncertainties. Assuming the independence of the impacts and probabilities cited above, it is possible to create by multiplication a matrix of joint impacts and joint probabilities.

Confidence Ranges

To estimate confidence in the estimates of water demand the water use impacts which fall within probability ranges of 95 percent for 1990, 90 percent for 2000, and 85 percent for 2020 were calculated and mapped.

- For 1990, the range which incorporated 95 percent of estimated uncertainties was ±28 MGD (±7 percent) based on the capacity planning estimate of 393 MGD. This included ±9 MGD for domestic use, ±11 MGD for nondomestic use, and ±8 MGD for related unaccounted-for water.

- For 2000, the range which incorporated 90 percent of estimated uncertainties was ±38 MGD (±9 percent) on the capacity planning estimate of 409 MGD for the 44 MDC communities. This included ±13 MGD for domestic use, ±15 MGD for nondomestic use, and ±10 MGD for related unaccounted-for use.

- For 2020, the range which incorporated 85 percent of estimated uncertainties is ±65 MGD (±14 percent) on the capacity planning estimate of 453 MGD for the 44 MDC communities. This includes ±21 MGD for domestic use, ±26 MGD for nondomestic use, and ±18 MGD for related unaccounted-for use.

FORECAST OF THE CAPACITY PLANNING ESTIMATE

Table 15 identifies the capacity planning estimates for 1990, 2000, and 2020, as well as the figures used for 1980. In summary, the 1990 capacity planning estimate of 393 MGD represents a 15 percent increase above the 1980 use of MDC water. The uncertainty around this estimate is represented by a range of 365-421 MGD. The 2020 capacity planning estimate of 453 MGD is 30 percent above the 1980 use of MDC water and falls within an uncertainty range of 388-518 MGD.

These capacity planning estimates do not include estimates of potential water demand reductions which could result from the various demand management strategies being studied.

Table 15. MDC Projected Base Demand and Capacity Planning Estimate (MGD)

	1980	1990	2000	2020
URRENT USERS:				
Forecast domestic	143.0	137.8	135.8	141.0
Adjustment for meter replacement	-	0.8	0.7	0.8
Metered domestic	143.0	138.6	136.5	141.8
Forecast nondomestic	119.3	128.4	136.4	155.8
Intertown transfers	1.3	1.4	1.4	1.4
Adjustment for meter replacement	-	1.8	1.8	2.0
Metered nondomestic	120.6	131.6	139.6	159.2
Domestic meter underregistration	8.4	7.3	7.2	7.5
Nondomestic meter underregistration	13.4	12.7	13.5	15.5
Unmetered public	6.4	6.5	6.5	7.0
Recoverable leakage	25.6	9.9	11.8	20.0
Other unaccounted-for	52.0	52.0	52.0	52.0
Total unaccounted-for	105.8	88.4	91.0	102.0
Total 44 communities	370.0	358.6	367.1	403.0
Special users—nondomestic	5.5	5.3	5.4	5.7
Special users—system use	30.1	21.0	21.0	21.0
Total demand	405.6	354.9	393.5	429.7
Less: Local Supplies (less Worcester from Quinapoxet)	(62.5)	(62.4)	(64.3)	(68.7)
Lynn Deficit		0.0	0.5	2.7
Drought—additional demand		2.5	2.5	2.5
Drought—reduced local supplies		2.5	2.5	2.5
BASE DEMAND ON MDC	343.1	327.5	334.7	368.7
Additional legal obligations[2]		53.2	53.6	53.3
Less: Amount included under drought (reduced local supplies)		(2.5)	(2.5)	(2.5)
Additional users (deficits of other potential future users)[3]		3.7	4.0	5.2
Contamination contingency (not included under additional legal obligations)[4]		10.8	18.7	28.1
ADDITIONAL POTENTIAL DEMAND		65.2	73.8	84.1
Uncertainty in Growth and Use Factors				
- Domestic		±9.0	±13.0	±21.0
- Nondomestic		±11.0	±15.0	±26.0
- Unaccounted-for[5]		±8.0	±10.0	±18.0
Uncertainty Range		365–421	371–447	388–518
CAPACITY PLANNING ESTIMATE		393	409	453

[1] Includes sales to General Electric in Lynn, as well as special users supplied directly by the MDC.
[2] These represent the amount of water which the MDC is obligated to supply on request to different groups of towns and are detailed in the section on "Additional Potential Demands on the MDC."
[3] Detailed printouts showing deficits by town are included in Appendix B-2.
[4] This amount takes into account the possibility that local supplies of entitled, eligible, and "feasible" users may become contaminated and result in additional demand, and is detailed in the section on Contamination Contingencies.
[5] Uncertainty in unaccounted-for is based only on the change in unaccounted-for attributable to estimated uncertainty in metered demand.

Chapter 2.
Domestic Water Use

INTRODUCTION AND SUMMARY

The purpose of this chapter is to describe:

- the components of domestic water use (nonseasonal and seasonal);
- the formulation of the domestic water use equations, including both per capita and per household use factors for different kinds of occupied housing units;
- the projections of population/households and associated water use factors that were used to forecast domestic water use; and
- the uncertainties in the domestic forecasts that are associated with uncertain growth and use factor estimates.

Domestic water use includes all metered water used in homes and apartment buildings, but does not include residential types of water use in hospitals, universities, and other institutions. Five different sources were used in making the domestic use estimates and forecasts:

1. a statistical analysis of past domestic water use in all MDC communities (both monthly and annually);
2. analyses of more than 5,000 individual household water accounts, including case studies of 547 individual household accounts for different types of housing in different neighborhoods in Milton and Melrose;
3. studies and analyses available in the literature;
4. interviews with water department superintendents, plumbing suppliers, appliance manufacturers, and pool and irrigation system installers; and
5. an independent assessment of changing water using technologies, standards, regulations, and practices.

For the 44 MDC communities, 1980 domestic water use totalled 143 MGD (17 MGD of seasonal outdoor use, 82 MGD of indoor bathroom-related use, and 44 MGD of other nonseasonal use). About 65 percent of this total was estimated to be population-related and about 35 percent household-related.

Population was forecast to increase by about 15 percent over the next 40 years in the MDC communities, while households will increase by 21 percent. Most domestic use factors were estimated to decline by 10 to 20 percent over the next 40 years, due to the new plumbing code which requires water-saving toilets and showerheads, and due to changing appliance standards for dishwashers and washing machines. These two offsetting forecasts were considered in the projections that domestic water use would remain relatively constant over the next 40 years in the 44 MDC communities. This forecast indicated a decline in Boston, which will be offset by minor increases in most other communities. For the 36 non-MDC communities studied, metered domestic water use was forecast to increase from 50.7 MGD in 1980 to 58.9 MGD in 2020.

The uncertainties associated with both population projections and water use factor estimates and forecasts were also examined. A range of ±21 MGD around the 2020 domestic water use forecast of 141.8 MGD for the 44 MDC communities incorporated an estimated 85 percent of uncertainties (±9 MGD around the 2020 forecast of 58.9 MGD for the 36 non-MDC communities). Table 16 summarizes the key factors influencing domestic water use.

COMPONENTS OF DOMESTIC WATER USE

In this analysis, domestic water use, which is about one-half of metered use and one-third of total use in the MDC communities, was categorized as either nonseasonal or seasonal. Nonseasonal, in-home usage includes toilet flushing, showering, bathing, and other bathroom uses; dish washing and other kitchen use; and laundering. Seasonal usage occurs primarily in such outdoor activities as lawn watering, gardening, automobile washing, and pool filling.

NONSEASONAL USE

Nonseasonal domestic use averages 80 to 90 percent of total domestic water use. It represents year-round bathroom, laundry, and kitchen use of water. It is primarily affected by the numbers of people in the household but because of "shared" water uses, such as laundry, dish washing, and general house cleaning, this nonseasonal domestic consumption is also affected by the numbers of households.

Per Household Usage Versus per Capita Usage

Case studies and literature reviews suggest that household water use does not increase (or decrease) as rapidly as household size. In small households, overall consumption per person is higher than in large ones. The demand simulation model, therefore, was formulated to treat

Table 16. Domestic Water Use Estimates & Forecasts

Domestic Water Use Component	1980 Metered Domestic Use (44 MDC Communities)	Estimated 1980 Use Factor	Estimated Change in Activities (1980-2020)	Estimated Change in Use Factors (1980-2020)
Outdoor seasonal use	17 MGD	2 gal/cap/day	population +15%	no change
		4 gal/m.f./day[1]	households +21%	no change
		15 gal/s.f./day[1]		no change
Bathroom use	82 MGD	55 gal/cap/day	population +15%	decline of about 15% for population living in existing units, 25% for population living in net new housing units[3]
Other indoor domestic use	44 MGD	10 gal/m.f./day[2]	households +21%	decline of about 8% in existing units, 10% in net new units[4]
		20 gal/s.f./day[2]		
TOTAL DOMESTIC USE	143 MGD			

	1980 Estimates		1990 Forecasts		2000 Forecasts		2020 Forecasts	
	44 MDC (MGD)	36 Non-MDC (MGD)	44 MDC (MGD)	36 Non-MDC (MGD)	44 MDC (MGD)	36 Non-MDC (MGD)	44 MDC (MGD)	36 Non-MDC (MGD)
Base domestic water use forecast	143.0	50.7	138.6	50.9	136.5	53.1	141.8	58.9
Additional domestic demand during extended droughts			2.5	2.0	2.5	2.0	2.5	2.0
Recommended ranges for incorporating[5] estimated uncertainties								
85% of uncertainties			±6	±2	±14	±5	±21	±9
90% of uncertainties			±10	±3	±18	±7	±26	±11
95% of uncertainties			±13	±4	±20	±8	±29	±12

[1] 30 gal/single-family household/day for high-income communities, 7.5 gal/single-family household/day for low-income communities.
[2] 40 gal/single-family household/day for high-income communities, 10 gal/single-family household/day for low-income communities.
[3] This assumes a 30% reduction in toilet flushing use where low-flush toilets installed (50% replaced by 2020), and a 25% reduction in shower use where low flush showerheads are installed (90% replaced in 2020).
[4] This assumes that energy- and water-saving clothes washers save 20% of water used (75% replaced with these appliances by 2020) and that energy and water saving dishwashers save 15% of water used (75% replaced by those appliances by 2020).
[5] Use of a 95% certainty level in 1990, 90% in 2000, and 85% in 2020 was advised.

Source: Arthur D. Little, Inc.

nonseasonal domestic consumption as a function of the number and type of occupied housing units (equivalent to households), as well as the number of persons.

It was estimated that the people-related or per capita component represented 75 percent of nonseasonal domestic consumption, and that dwelling- or household-related use represented the remaining 25 percent. This estimate was based, in part, on case study findings and regression analysis on data collected on 547 sample households in single-family and small multi-family dwelling units in Milton and Melrose, on data on about 700 household accounts in five other communities, the total use and reported domestic use in all MDC communities, and, in part, on findings reported in the literature.

SEASONAL USE

For the purposes of this study, seasonal use was defined as the difference between water use in May through October and November through April. It was considered to be almost entirely domestic (primarily outdoor watering) and was forecast as a function of the number and type of households, varying between 10 to 20 percent of the domestic total.

Although peak summer seasons include some nondomestic consumption in golf courses, parks, cooling systems, and the like, there are also counter-seasonal influences, such as main breaks and sewer flushing during off-season months. The combination of these factors was not considered significant enough to substantially alter the peak seasonal patterns observed across communities. Moreover, because the pattern in relation to reported domestic use was so consistent between those communities whose consumption was nearly 100 percent domestic and most communities with a mix of industrial, commercial and other nondomestic uses, the total seasonal use was considered to be domestic.

Seasonal Use Adjustments for Housing Type/Income

Calculations of monthly data and samplings of household consumption in seven case study communities showed the seasonal use to be highest in those towns and parts of towns with single-family homes in large lot and/or higher income areas. In seven case study towns (Belmont, Framingham, Melrose, Milton, Needham, Quincy, and Waltham), the large lot, higher income areas had 1.5 to 2.0 or 3.0 times higher household and per capita consumption levels than other single-family areas in the community. Seasonal consumption was probably the chief reason for such disparities and for much of the difference in rates of consumption between communities. The demand simulation model,

therefore, was formulated to incorporate these differences as a function of housing type and income.

Seasonal Use Adjustments for Drought/Precipitation

An analysis on total monthly consumption reported by MDC communities from the early 1960s through 1980 was conducted. The data indicated a seasonal peak in water use in almost all communities during May through October in both wet and dry years. The seasonal component for each community was obtained by multiplying the six off-season months by 2.0 and subtracting the product from the total annual consumption. The remainder varied between 5 and 10 percent of total consumption in most communities and varied also from year to year, depending on precipitation (see Table 17).

Seasonal use was considerably higher in dry years. Seasonal water use in 1980, for example, was nearly double that of 1972. In 1980, a dry year, seasonal use averaged 10 to 15 percent higher than for years with normal summer precipitation. A seasonal use adjustment was necessary, therefore, in projecting future average annual use, as well as use during extended drought periods.

STATISTICAL ANALYSIS, CASE STUDIES, AND LITERATURE FINDINGS

Data from the meter records of nearly 1,200 households, including single-family and small multi-family units, in addition to records for about 4,000 appartments units, were compiled and analyzed. During Phase 1, six case study towns were sampled; and in Phase 2, a seventh community, Melrose, was surveyed as well. (More detailed results are included in Appendix D.)

Community Statistical Analyses

Statistical analysis of data in MDC communities over the past 20 years and a cross-sectional analysis of water consumption in 50 "residential" communities in the study area in 1980 revealed that the only variables which seemed significant in explaining domestic use differences among communities were seasonal use, population, and households--particularly single-family households. Other influences, such as per capita income or persons per square mile, were found to be of far less consequence. Because population and households are so interdependent, no way was found to statistically isolate domestic consumption attributable to households as water-consuming units, even though such a relationship was suggested from other sources. However, the data did indicate a strong correlation (r^2 values of 0.97 and 0.96) between 1980 population and 1980 households and community domestic

Table 17. Seasonal Water Use* as a Percentage of Total Use, 1972-1980

Town	1972	1975	1976	1977	1978	1979	1980
Arlington	3.2	4.6	8.9	10.7	12.0	8.4	6.8
Belmont	7.2	17.8	17.8	8.2	10.0	11.6	9.8
Boston	(0.6)	3.4	8.4	1.8	2.4	1.0	2.5
Brookline	3.4	8.3	9.4	7.3	9.0	7.6	7.6
Chelsea	0.2	0.8	8.8	2.0	1.4	(1.4)	6.4
Everett	4.1	8.0	9.8	3.4	4.4	4.6	4.6
Lexington	4.4	14.8	8.1	6.4	12.0	12.0	17.6
Lynnfield Water District	11.8	28.8	15.6	6.2	10.8	7.8	5.0
Malden	2.8	(13.4)	4.8	4.2	5.4	6.6	4.1
Marblehead	3.8	11.2	11.4	11.1	9.9	9.4	11.2
Medford	3.0	9.0	6.4	2.2	0.6	(3.0)	(3.6)
Melrose	4.4	13.4	11.4	8.8	8.4	9.8	10.0
Milton	6.0	10.8	7.3	2.2	5.6	0.0	5.4
Nahant	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A
Newton	7.3	13.1	14.0	12.8	12.1	11.4	13.8
Norwood	5.6	6.8	4.4	5.0	8.8	3.4	7.4
Quincy	1.6	4.2	4.0	2.9	1.2	(2.0)	1.2
Revere	8.1	16.4	16.0	5.4	5.4	5.4	2.2
Saugus	4.8	8.7	(0.6)	(2.4)	2.9	4.6	3.3
Somerville	1.8	4.5	6.0	4.0	3.0	3.2	1.8
Stoneham	9.8	13.6	10.6	7.8	5.5	0.0	(2.8)
Swampscott	14.5	7.4	11.0	15.1	9.2	8.0	9.2
Waltham	4.3	6.3	(10.4)	(8.0)	7.8	6.6	5.7
Watertown	6.3	7.7	8.4	5.1	2.6	0.0	8.2
Winthrop	5.0	5.0	2.8	7.3	3.6	3.8	5.3
Average of 17 MDC communities which do not have negative seasonal use exceeding 2.0 or positive seasonal use exceeding 20)	5.0	9.0	9.3	6.9	7.0	5.8	7.6
Characterization of Summer Precipitation Based on Stream Flows	W	D	D	N	N	W	D

*Seasonal use = May-October water use minus November-April water use.

Source: Arthur D. Little, Inc.

consumption.[1] The case study samplings, therefore, concentrated on compiling data on consumption in single-family and multi-family housing types.

Seven Case Study Communities

The samples found considerable variability in water use from household to household, with a large part attributable to household size and seasonal use. Other reasons for the variation, although not determined explicitly in the samples, were the age of occupants, length of time spent at home, incomes, lifestyles, water conservation activities, and availability of swimming pools and water-using appliances, such as clothes washers, water pressure, leaks, as well as meter problems.

Sample water use averages for the seven case study towns fell between 131 to 547 gallons per day per household. The range narrowed considerably when large-lot, high-income households were discounted and when household size was accounted for, such as in the Melrose and Milton data. For small-lot, moderate-income single-family and small multi-family (two to four household units), household consumption was 131 to 228 gallons per day and 58 to 93 gallons per person (an average of about 70 gallons per person). For large multi-family households (five or more units in a structure), average consumption, over nearly 3,900 units, was 169 gallons per household and 79 gallons per capita. Table 18 summarizes sample averages found in the case studies.

Milton and Melrose Case Studies

In two towns, Milton and Melrose, reasonably similar in socioeconomic and community development characteristics, and having a representative mix of housing types and lot sizes, data were collected on the number of persons in each housing unit sampled, as well as their household water use.

Samples of households in Milton and Melrose indicated that there were separable person-related and household-related components of domestic consumption. Although there was considerable variability,[2] the general pattern across all housing types surveyed indicated that the household component was larger in smaller households, but that the per capita component seemed to account for most water use in all households--certainly all those above three persons in residence level.

Table 19 indicates percentages for the calculated person-related component of household consumption for various household sizes. The figures were derived from linear regression equations fitted to the Melrose and Milton data.

ible 18. Average Household Water Use in Seven Case Study Towns

Housing Type	No. in Sample	Gal/HH/Day Range	Gal/HH/Day Average	Gallon/Person/Day* Range	Gallon/Person/Day* Average
SF, large lot	389	307-547	380	107-127	116
SF, small lot	376	131-228	182	58-80	68
2-, 3-, 4 Family	428	140-154	124	62-93	73
MF, 5 or more	3,859	103-317	169	50-204	79

*For single-family and small multi-family (less than five units), the data came from Milton and Melrose.

Source: Arthur D. Little, Inc.

Table 19. Person-Related Percentage of Household Consumption

	Percentage Person-related Consumption for Persons per Household of				
Housing Type	1	2	3	4	8
Melrose, lg lot, SF	44	61	70	76	8
Milton, lg lot, SF	37	53	63	70	8
Melrose, sm lot, SF	25	40	50	57	7
Milton, sm lot, SF	63	77	84	87	9
Melrose, 2-4 F	48	65	73	79	8
Average, All	43	59	68	74	8

Source: Arthur D. Little, Inc.

To release the influence of other factors, such as outdoor use, swimming pools, and meter problems, only those households with less than 100 gallons per capita were included in this particular analysis. In making this assumption, the large-lot and small-lot, single-family and small multi-family consumption data were more directly comparable.

As indicated in Table 19, the person-related component of total household consumption for two-person households in the sample varied from 40 to 77 percent among the housing types, with the simple unweighted average for all types being 59 percent. For four-person households, the range was 57 to 87 percent, with the average at 74 percent. This range of household sizes--two to four persons--predominated in communities across the study area.

Figure 11 illustrates the overall average person-related and household-related components estimated for the several household types included in the Milton and Melrose case studies. To construct Figure 11 required merging of widely varying data. By limiting the analysis to only those household samples with less than 100 gallons per capita per day, the variability in the original sample data was significantly decreased. The original sample size was reduced approximately 17 percent; however, it remained at 454 households, still relatively large.

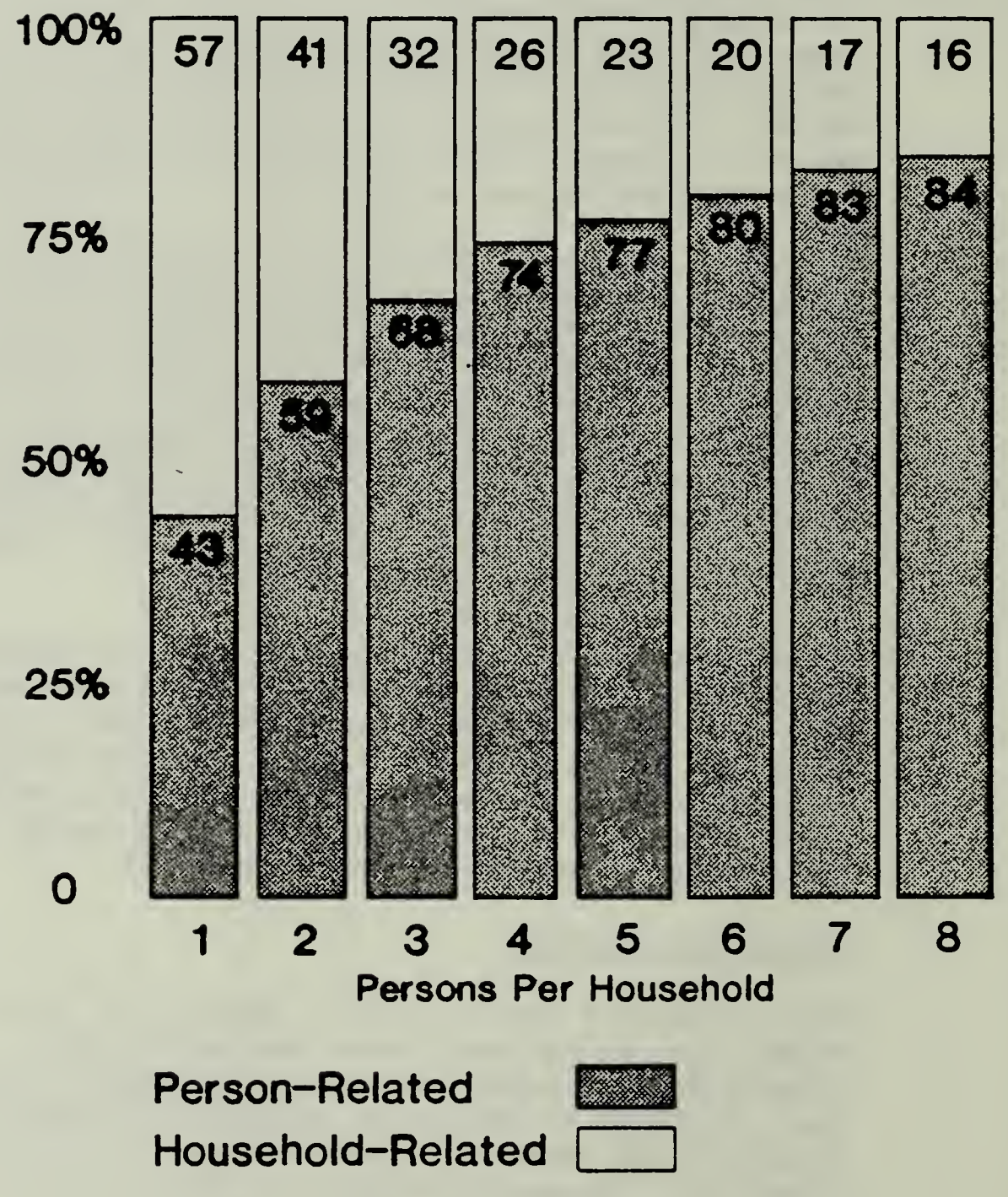
Notwithstanding some data limitations, the findings from Milton and Melrose case studies provided extremely important basic data for construction of a demand simulation model applicable to the MDC area. The statistical analysis and case studies demonstrated the need for a relatively heavy weighting of population and single-family units in the disaggregated demand simulation model.

Literature Findings

Most literature sources tend to quote work done by Howe and others for the National Water Commission[3] when proportioning assumed components of domestic, nonseasonal use. Findings of studies of individual households in Nevada,[4] EPA sources,[5,6] and articles in professional journals,[7,8] generally support the earlier work, while adding some refinement with more recent data. All of these sources were used to develop breakdowns of nonseasonal use that are presented in Table 20. The earlier literature indicated that for all households, toilet flushing may be on the order of 40 to 45 percent of in-house use, bathing (including showering), approximately 30 percent; and laundry and dishwashing, 20 percent. Studies of a handful of families in Nevada[9] and a recent review of the literature indicated, however, that the toilet flushing

Figure 11.

Person–Related and Household–Related Components of Household Water Use



component may be lower and the bathing/showering higher than the older literature suggests. The assumed percentages used in this study, therefore, are lower for toilet flushing and higher for showering for that reason.

In Table 20, the bathroom-related items were estimated to account for 75 percent of nonseasonal domestic consumption and were considered to be a direct function of the number of persons in households. The latter three items, laundry and kitchen-related, were considered to be more shared activities which theoretically relate both to numbers of households and number of people or household size.

ORMULATIONS OF DOMESTIC
ATER USE EQUATIONS

THE APPROACH TO MODELING SEASONAL AND NONSEASONAL DOMESTIC USE

Existing domestic consumption in MDC towns was reported, and it was considered generally to be reliable in most communities after adjustments for the large number of small nondomestic users often included (see Appendix A). For the non-MDC towns and cities, the reporting of domestic use was much less reliable and was often unavailable. The demand simulation model, therefore, includes a 1980 estimating equation which provides 1980 domestic water use estimates for each MDC town (including an unexplained residual of reported use). The estimating equation was then used to estimate 1980 domestic water use in non-MDC communities.

Future domestic water use was considered to be more a function of the change in water use technologies and user composition than a function of alterations in the underlying water use habits of people. Future domestic consumption was anticipated to change as residents complied with building and plumbing codes that stipulate low-flush toilets and low-flow showerheads and as households purchased toilet dams and other water-saving and, in most cases, energy-saving fixtures and appliances (low-flow showerheads, clothes washers, and dishwashers).

The demand simulation model is able to demonstrate the water use implications of a changing population and housing stock, while incorporating explicit assumptions about the technology and efficiency of various water-using fixtures and appliances. It can also incorporate explicit changes in water use practices and conservation and can be used to test sensitivities under alternate assumptions about growth and use factors.

Table 20. Size of Nonseasonal Domestic Water Use Components

	Percentage Range in Literature	Percentage For This Study
Toilet Flushing	15-45	38
Showering	15-50	22
Bathing and Other Bath	6-27	15
Laundry	14-35	15
Dish Washing	2-6	5
Other Kitchen	4-18	5
		100

Source: Arthur D. Little, Inc.

EXPLANATORY EQUATIONS AND USE FACTORS FOR 1980 DOMESTIC WATER USE

For simulating 1980 consumption in MDC communities, domestic water use factors were developed for the seasonal, nonseasonal, and person-related/household-related uses. Water use factors were stated in terms of either per capita or per household relationships. Moreover, to account for apparent variations in the water use of single-family households in different income groups, adjustments were made to the basic per household factors to be applied to high-, medium-, and low-income groups of communities.

The 1980 estimating equations used in the demand simulation model are presented below:

- $$\frac{\text{1980 Nonseasonal Use} = 55\ \text{gcd}^{(1)} + 10\ \text{gmfhhd}^{(2)} + 20}{\text{gsfhhd}^{(3)} + E^{(4)}}$$

  (1) gallons per capita per day--This is the in-house, basically sanitary use attributable to people in the household. It is derived from the average per capita consumption for single-family, small-lot and multi-family households. It is assumed there is little seasonal use by this group and that three-quarters of this average, 73 GCD, is in-home, person-related use. The latter proportion is a result both of literature reviews and regression analysis of Milton and Melrose sample data.

  (2) gallons per multi-family household per day--The major assumption is that in multi-family units, clothes washers and dishwashers are less frequently in use than in single-family housing units.

  (3) gallons per single-family household per day--This figure is an average for moderate-income households; for high-income households, it is estimated to be 40 gallons per day, and for low-income households, 15 gallons per day. The varying use factors attempt to account for significantly different water use found in large-lot, higher-income households than in other household types.

  (4) The error and unexplained factor allows for a numerical estimate of the difference between predicted and reported domestic consumption in 1980.

- $$\frac{\text{1980 Seasonal Use} = 2\ \text{gcd}^{(1)} + 4\ \text{gmfhhd}^{(2)} + 15}{\text{gsfhhd}^{(3)} \times \text{Padj}^{(4)} + \text{E}^{(5)}}$$

(1) gallons per capita per day--Accounting primarily for more seasonal showers and other increased summer sanitary use.

(2) gallons per multi-family household per day--Accounting for the minor outdoor use associated with apartment units.

(3) gallons per single-family household. An average figure to reflect the higher per household outdoor watering component in single-family areas found in both the seasonal analysis and the seven case study town samplings. The model follows the assumption that in higher income areas, the figure is double (30 ghd) and in lower income areas one half the average (7.5 ghd).

(4) The model provides for a precipitation adjustment to be related to wet year/dry year assumptions that would affect seasonal use. For example, 1980 was a relatively dry summer with a precipitation adjustment estimated at 1.10. Adjustment factors reflect the ratio of seasonal use in 1980 to seasonal use in previous years of more normal summer precipitation, as determined by an analysis of both streamflow and rainfall data.

(5) The error or unexplained factor allows for a quantity to be calculated measuring the difference between seasonal use calculated by the model and by analysis of actual monthly data.

For most MDC communities, these equations resulted in a difference of less than 15 percent between domestic use estimated by the model and that reported to MDC for 1980. (In a third of the communities representing 65 percent of MDC domestic use, the difference was less than 9 percent.) Because there was no way to identify the causes of such differences, they were identified as unexplained domestic use and were also forecast as a component of use in each community. For reasons described in Appendix A, the report use of several communities (19 in all) was adjusted where appropriate. Table 21 shows the adjusted reported domestic use for 1980, the estimated use, the unexplained use, and the unexplained use as a percentage of total adjusted use.

Table 21. Adjusted Reported Domestic Water Use Compared to Domestic Water Use Estimated by Equation 1980

Town	Adjusted Reported Domestic	Domestic Use Estimated by Model	Domestic Use by Model Equation Unexplained	Unexplained as Percent of Adjusted Domestic
Arlington	1,164	1,151	(13)	(1.1)
Belmont	681	676	(5)	(0.8)
Boston	13,050	12,032	(1,018)	(7.8)
Brookline	1,807	1,314	(493)	(27.3)
Chelsea	657	567	(90)	(13.7)
Everett	803	846	43	5.4
Lexington	902	818	(84)	(9.3)
Lynnfield Water District	79	94	15	18.9
Malden	1,091	1,210	119	10.9
Marblehead	570	569	(1)	(0.2)
Medford	1,292	1,419	127	9.8
Melrose	700	721	21	3.0
Milton	621	707	86	13.8
Nahant	109	96	(13)	(12.0)
Newton	2,196	2,131	(65)	(3.0)
Norwood	615	703	88	14.3
Quincy	2,068	1,924	(144)	(7.0)
Revere	857	966	109	12.7
Saugus	600	600	0	0.0
Somerville	1,918	1,720	(198)	(10.3)
Stoneham	425	513	88	20.7
Swampscott	438	373	(65)	(14.8)
Waltham	1,431	1,257	(174)	(12.2)
Watertown	830	798	(32)	(3.9)
Winthrop	518	436	(82)	(15.8)
Fully Supplied Members (25)	35,422	33,540	(1,882)	(5.3)
Chicopee	1,422	1,247	(175)	(12.3)
Clinton	400	273	(127)	(31.8)
South Hadley Fire District #1	354	351	(3)	(0.8)
Southborough	129	174	45	35.2
Wilbraham	203	234	31	15.3
Fully Supplied Nonmembers (5)	2,508	2,279	(229)	(9.1)
Cambridge (0.4%)[1]	1,900	1,945	45	2.4
Canton (48%)	585	490	(95)	(16.3)
Needham (30%)	769	787	18	2.4
Peabody (27%)	1,171	1,111	(60)	(5.1)
Wakefield (67%)	672	595	(77)	(11.4)
Wellesley (0)	659	674	15	2.2
Weston (100%)	353	257	(96)	(27.2)
Winchester[2]	620	565	(55)	(8.8)
Woburn (19%)	1,068	1,004	(64)	(6.0)
Partially Supplied Members (9)	7,797	7,428	(369)	(4.7)
Framingham ( )	1,725	1,503	(222)	(12.9)
Leominster (22%)	700	719	19	2.7
Marlborough (91%)	831	679	(152)	(18.3)
Northborough (10%)	173	230	57	32.7
Worcester (0)	2,710	3,451	741	27.3
Partially Supplied Nonmembers (5)	6,139	6,582	443	(7.2)
TOTAL USE ALL MDC USERS	51,866	49,829	(2,037)	(3.9)

[1]Percent of municipal supply received from the MDC in 1980.
[2]1980 use not representative of usage patterns.

Source: Arthur D. Little, Inc.

POPULATION/HOUSEHOLD PROJECTIONS

The activity levels which must be forecast to estimate future domestic use are:

- population (by community, by occupancy of new versus old housing units); and
- households (by community, by occupancy in single-family versus multi-family units, by relative income level)

STATEWIDE POPULATION FORECASTS

There are a wide variety of forecasts available for these population and households; and there is also considerable uncertainty surrounding long-term, 20- to 40-year, forecasts. The rate of reduction in U.S. fertility rates over the last 10 to 15 years has continued to exceed most forecasts as has the rate of increase in U.S. life expectancy. Whether these trends will continue, or level off, or reverse themselves nationally is difficult to say; and cases can be made for a wide variety of perspectives both for the United States and Massachusetts. The same can be said for both U.S. inmigration and particularly net migration to or from Massachusetts or the Boston Metropolitan area.

The relationship between economic development and employment opportunities and population and household formation is difficult to trace. But, as described in Appendix E, the M.E.P.A. model appears to be the best approximation of this dynamic and the range of uncertainties involved in forecasting the economic and demographic performance of Massachusetts relative to the rest of the country. Because of this fact and the fact that the M.E.P.A. model incorporates both very current and long-term historical data, its forecasts have been used in this study.

The statewide population forecasts under the mid-range control scenario for 2007 are summarized in Table 22, which also shows the extrapolation of these forecasts to 2020 (based on 2000-2007 rates of growth). The control forecasts are generally lower than the OSP forecasts developed for use in the §208 Statewide wastewater plans in 1978, and they are generally higher than the statewide rates of growth implied by the recently developed MAPC forecasts.

The statewide forecasts also represent a Massachusetts growth rate substantially below (about 30 percent below) the official U.S. population growth forecast. This relative growth rate over the next 40 years is generally consistent with the last 40 years of experience in

able 22. Population Forecasts, 1980–2020 (in thousands)

	1980	1990	2000	2007	2020	Cumulative % Change 1980-2020	Annual % Change 1980-2020
1. US Census Bureau Forecasts of US Population							
- Series II (Control)	222,480	243,520	260,900	270,470	289,200	30.0	0.66
2. M.E.P.A. Forecasts of Massachusetts Population							
- Control	5,740	6,137	6,418	6,573	6,869	19.7	0.45
3. M.E.P.A. Forecasts as Allocated to 44 Current MDC Communities							
- Control	2,178	2,278	2,353	-	2,439	12.0	0.28
4. M.E.P.A. Forecasts as Allocated to 36 Non MDC Communities in Planning Area							
- Control	742	808	883	-	999	34.6	0.75

Source: Arthur D. Little, Inc.

Massachusetts, and the high and low ranges incorporate most of the shorter term situations that have developed in any given decade during the last 40 years.

ALLOCATIONS OF POPULATION GROWTH TO STUDY AREA COMMUNITIES

The estimated population growth used for individual planning area communities was based on the relative community growth rates used in the recent MAPC and §208 forecasts which also incorporated information about the existing housing stock, zoning, community attractiveness, and residential development potentials in each community. Because the M.E.P.A. "low" forecast was about equal to the average of the OSP and MAPC forecasts, these averages were used to establish the community allocation under the low forecast and were then adjusted proportionately for the other forecasts.

HOUSEHOLD AND HOUSING UNIT GROWTH

Households and housing unit growth was derived, community by community, by keeping relative household sizes constant and by having net new housing units divided between single-family and multi-family units in the same proportion as represented by the building permit data for the past 10 years.

FUTURE DOMESTIC USE FACTORS

In future years, reductions in nonseasonal domestic water use factors are anticipated, as compliance with plumbing codes requiring reduced water consumption in toilets and showers in new construction and renovations takes effect. Moreover, in existing housing units, water-saving devices may become more acceptable to more households. The seasonal use component, however, is not expected to change significantly.

The following assumptions underlie the estimated changes in domestic use factors.

FUTURE NONSEASONAL PER CAPITA USE FACTORS

The per capita use factor will decline as existing units are rehabilitated and new units are constructed in accordance with the new plumbing code with all water-saving features. The potential conservation savings which are illustrated in Table 23 are assumed to result from low-flush toilets and from low-flow showerheads or flow restrictors.

ble 23. Estimated Reduction in Per Capita Use Due to Low-Flow Toilets and Showerheads

Nonseasonal Sanitary	%	1980 GCD	GCD With Required Water Saving Fixtures*
Toilet Flushing	50	27.5	19.0
Showering	30	16.5	12.5
Bathing and Other Bath	20	11.0	11.0
	100	55.0	42.5

*The savings are based on:

- New low-flush toilets reducing flushes from 5 to 3.5 gallons, a 30 percent reduction with no change in practices;
- Shower heads reducing consumption from 5 to 6 gallons per minute to 2.75-3.0 gallons per minute, but with some change in practices and an estimated reduction in water use per shower of 25 percent. (This reduction is based on field tests as discussed in the demand management task report.)

Source: Arthur D. Little, Inc.

Future per Capita Domestic Use Factors for New Additions to the Housing Stock

It was assumed that all new housing units constructed after 1980 will satisfy plumbing codes as related to bathroom use. Telephone calls to plumbing supply houses (reported in Appendix D) indicated that all new toilets, showerheads, and most faucets now produced by manufacturers for Massachusetts delivery are of the lower water-using types. Because of this, all new housing units were assumed to have a per capita use factors of 42.5 gpcd--a 25 percent reduction from the currently prevailing 55 gpcd.

Future per Capita Domestic Use Factors for the Existing Housing Stock

It was also assumed that, by the year 2000, half of all housing units which now exist will have code-required, water-efficient bathroom fixtures, with low-flush toilets, toilet dams, or other flush reduction devices and low-flow showerheads. It is expected that one-fourth of the units will have become water-efficient as part of renovation and one-fourth because of replacement of worn out or broken fixtures. In support of this assumption, it should be noted that, in 1970, 73 percent of the housing stock in the MDC district was over 30 years of age (although some of these units had newer bathrooms); and by the year 2000, a similar percentage would be over 60 years of age. Given the age of housing and current rates of rehabilitation, a 25 percent figure (1 percent per year) for the next 20 years appears reasonable.

From the age of housing, it was also assumed, conservatively, that the average bathroom is 15-20 years old. Literature sources indicate the useful life of a showerhead is on the order of 15 years.[10] From plumbing-supplier interviews, it was learned that the average toilet is replaced once in 40 years because of breakage or wear. It may also be noted from interviews with plumbing suppliers that the installation of showerheads seems tied to replacement of hot-water heaters whose useful lives vary between 6 and 13 years,[11] depending on the manufacturer and the corrosiveness of the water. When a plumber installed a replacement hot water heater, it was said, the householder typically was persuaded to install a water-saving showerhead as well in the interests of further energy and water efficiencies.

It was anticipated, therefore, that by 2020 nearly all existing showerheads (90 percent) will have been replaced with new code-required, low-flow showerheads because that is all that will be available; and this replacement will have occurred either to save water or energy or simply, of

necessity, because the old one has worn out. By 2000, it is expected that half of all showerheads in existing households will be of the low-flow type and, by 1990, 20 percent, simply due to replacement of a worn-out unit.

For toilets, similar reasoning indicated a significant number are currently old or will be beyond their service life by 2000. Plumbing supply houses in Boston, Somerville, Medford, and other older urban communities indicated hundreds being sold each year by each supplier. While it was not anticipated that toilets will be replaced to save water, a reasonable rate of replacement to account for breakage, obsolescence, wear and tear was assumed. By 2000, it was anticipated that 25 percent of all existing toilets will be replaced by water-savers.

With respect to toilet dams or other flush-reducing devices, little or no market penetration was anticipated. Similarly, no voluntary retrofitting of showerheads or water-saving faucet aerators is assumed in the baseline, although there was evidence of the public beginning to respond to advertising, promotional activity, and increased availability of these products in discount, hardware, and retail building supply stores.

It was assumed that retrofitted housing units will not be quite so water efficient as brand new ones with the latest plumbing fixtures. The average per capita bathroom use in a retrofitted unit is therefore assumed to average 45 GCD as opposed to 42.5 GCD anticipated in new construction.

FUTURE NONSEASONAL PER HOUSEHOLD USE FACTORS

The per household water use factors change primarily as more water-efficient clothes washers and dishwashers are installed and/or replaced in new and existing housing units. The assumptions with regard to these appliances are explained below.

Future Clothes Washing Use Factors

According to the 1960 Census, approximately 68 percent of all households in the Boston Metropolitan area had some type of automatic or semi-automatic clothes washer. By 1970, the percentage had increased to just over 69 percent. In the City of Boston, the comparable statistics are 51 percent in 1960 and 53 percent in 1970. In the Metropolitan area outside of Boston, the data for 1960 and 1970 indicate no further market penetration, with 75 percent of households having a clothes washing appliance in both Census years. Although 1980 Census data are not yet available, no substantial changes in these percentages are anticipated.

- For the future, a judgment has been made that there will be no further market penetration of clothes washers. (A corollary to this is an assumption there will be no change in market share at laundromats.) The assumption is based partly on the fact it is difficult to convert an existing housing unit, especially large multi-family units, to accept a washer, and partly on the market penetration already achieved, particularly outside of Boston. New housing units probably would reflect this, with approximately 75 percent having clothes washers.

  Clothes washers in future years are estimated to save 20 percent of water on the average compared to present models. While there is a whole range of savings depending on supply pressure, load size assumptions, water level settings, cycle selection, temperature, suds-saving features, and machine configuration,[12] the average selected for the demand simulation model generally falls in the middle of the range. These machines also save hot water and energy and (in the absence of any data to make a projection) were assumed to maintain their current popularity, becoming standard by 2000 with 75 percent of new washers installed being of the water- and energy-saving type.

  Clothes washers were assumed to have a useful life of 15 years,[11] and it was further assumed that all clothes washers existing in 1980 will have been replaced by 2000 and 2020. Consequently, it was assumed that the portion of the nonseasonal household use factor attributable to clothes washing (about 40 percent) would decline by 15 percent (a 20 percent reduction in 75 percent of the clothes washers), resulting in an overall reduction of about 6 percent in the household use factor by 2000 and 2020.

Future Dishwashing Use Factors

In 1970, 18 percent of MDC district families had an automatic dishwasher. In the absence of any local data, a judgment has been made that, by the year 2000, 50 percent of households will have automatic dishwashers because of their relative ease to install, convenience, and comparatively low price. National data indicate dishwashers had increased their market penetration from the 7.1 percent of households having them in 1960, to 26.5 percent in 1970, and 43 percent in 1979.

Dishwashers were estimated to save 15 percent of water use in future years as compared to current models. As with clothes washers, there is a range of potential savings,[13] but the assumed figure lies in the middle of that range. Water-saving dishwashers are expected to become increasingly more acceptable in the marketplace because of

householders' desires to save energy as well as water. The assumption, as with clothes washers, is that by the year 2000, water-saving dishwashers will account for 75 percent of new units installed. Dishwashers, properly loaded and utilized, were assumed to be at least as efficient as washing dishes by hand. Although no specific data have been found on this point, such assumption appears reasonable and consistent with previous studies and reports.

Dishwashers were assumed to have a useful life of 15 years,[14] and it was further assumed that all dishwashers existing in 1980 will have been replaced by 2000 and 2020. Consequently, it was assumed that the portion of nonseasonal household use factor attributable to dishwashers (about 20 percent) would decline by 10 percent (a 15 percent reduction in 75 percent of the new dishwashers), resulting in an overall reduction of about 20 percent in the household use factor by 2000 and 2020.

Combined Reduction in Household Use Factors

Based on the above assumptions and assuming no other changes in technology or water use practices, the overall household use factor was reduced by 5.3 percent in 1990 and 7.9 percent in 2000 and 2020.

FUTURE SEASONAL USE FACTORS

Swimming Pools

Based on local and national statistics, swimming pools do not currently account for a significant proportion of domestic use in the area, and this is not expected to change drastically during the planning period. In the Northeast region, residential pools are owned by less than 2 percent of households on the average. Projecting regional trends since 1948 indicated that less than 5 percent of households would have swimming pools by 2020, assuming penetration of the Boston market is similar to overall growth in the Northeast.

However, calls to building departments in Boston and six other communities did not disclose any significant upward movement in new pool permits over the past several years; thus, it was not clear whether a continued penetration of the market at past rates was an appropriate assumption. (See Appendix D for more detail.)

To the extent that the number of pools in the 44 MDC communities service area can be extrapolated from regional and national data, an estimated 13,000 pools existed in 1980; and if there is continued market penetration, the

number could increase to 40,000 to 42,000 by 2020. Water for initial fills, spring filling of those drained for the winter, and make-up water for evaporation, leakage, and water lost through drains or maintenance probably amounts to approximately 1 MGD presently; and it might reach 3.3 MGD by 2020 if pool ownership continues to grow in accordance with past linear trends, which is considered unlikely. For the baseline forecast, no increase in swimming pool use was forecast.

Spas and Hot Tubs

The growth and impact on domestic water consumption of spas or small hot-water pools, either attached to an existing pool or as a separate unit, and of hot tubs are largely unknown at this point. The industry has grown from an estimated 54,000 units nationwide in 1977 to sales of 100,000 to 125,000 units in 1981.[15] The statistics do not indicate how many of these units have been installed in commercial applications as opposed to residential and what the regional sales breakdowns are. Unknown also is the effect climate and water heating costs may have on sales in this area, or if sales of such units would cut into the swimming pool market. If the extent of market penetration is similar to what swimming pools have been able to capture in this region, it is felt that spas and hot tubs will have little if any impact on domestic water consumption during the planning period.

Underground Sprinkler Systems

Calls to two of the three largest Massachusetts distributors of components for underground sprinkler systems indicated a growing New England market for these types of irrigation systems. The Washington, D.C.-based Irrigation Association indicated there are no statistics available on the number of systems that have been installed nationally or regionally. The two distributors contacted felt there had been thousands of systems installed in New England, and that as long as weather permitted, some 200 installers were installing systems currently at the rate of one or two per week. In the Cape Cod area, the most active area, two or three systems per day was said to be the installation rate of local contractors.

Industry sources claim that water is saved with use of the underground system as compared to water being delivered through a hose to an above-ground portable sprinkler. Because the installed system may be programmed to deliver the precise amount of water needed, when needed, and in the exact location and deliver it in the cool, relatively windless early morning hours, needless watering and reduction of evaporation losses can amount to 90 to 93

percent efficiencies. The more typical hose-delivered watering was said to be only 40 to 50 percent efficient.

While the industry sources undoubtedly are correct about the relative efficiencies, it is also true that lawn watering, even by the hose/sprinkler system, can be done far more efficiently if conscientiously controlled by the householder. Moreover, because of the simplicity and conveniences of the permanently installed system, there may be the tendency to water more frequently than with the portable hose/sprinkler system. On balance, however, the assumption was that household water use will neither increase nor decrease because of changed lawn watering practices, or the installation of permanent underground systems.

FUTURE DOMESTIC WATER USE FACTORS

The primary development in future domestic consumption is expected to be tied to technological change and the application of this in the plumbing code requirements and appliance standards. Likewise, people will replace fixtures because their old toilet or showerhead has wornout, or been broken and needs replacement. The assumptions stated in the previous sections take into account average in-use water-saving technology which may very well improve in the future. No future changes in technologies, plumbing codes, or appliance standards are assumed, nor is the introduction of new water-consuming devices which would tend to increase domestic consumption.

Most of the assumptions point toward a decline in total domestic consumption, unless there is a compensating growth in population and households. By being explicit, however, different assumptions and sensitivities may be tested. Unless new assumptions differ dramatically, the water use factors and domestic consumption levels derived from them are unlikely to change to any great degree. The domestic water use factors utilized in the disaggregated demand model are presented in Table 24.

DOMESTIC WATER USE FORECASTS

Forecasts of domestic water use include a base demand estimate (which is the adopted growth forecasts and the associated use factors), a capacity planning range (which is based on the assessments of the uncertainties on assumptions/estimates, and the range of forecasts necessary to incorporate 95 percent of potential uncertainties in 1990, 90 percent in 2000, and 85 percent in 2020.

Table 24. Forecast Domestic Water Use Factors, 1980–2020

Nonseasonal Domestic Use, Existing Units	1980	1990	2000	2020
Low-income Communities				
Population (gal/capita/day)	55.0	52.0	49.0	47.0
Single-family (gal/hh/day)	10.0	9.5	9.2	9.2
Multi-family (gal/hh/day)	10.0	9.5	9.2	9.2
Middle-income Communities				
Population (gal/capita/day)	55.0	52.0	49.0	47.0
Single-family (gal/hh/day)	20.0	18.9	18.4	18.4
Multi-family (gal/hh/day)	10.0	9.5	9.2	9.2
High-income Communities				
Population (gal/capita/day)	55.0	52.0	49.0	47.0
Single-family (gal/hh/day)	30.0	28.4	27.6	27.6
Multi-family (gal/hh/day)	10.0	9.5	9.2	9.2

Nonseasonal Domestic Use, New Units	1980	1990	2000	2020
Low-income Communities				
Population (gal/capita/day)	55.0	42.5	42.5	42.5
Single-family (gal/hh/day)	10.0	9.0	9.0	9.0
Multi-family (gal/hh/day)	10.0	9.0	9.0	9.0
Middle-income Communities				
Population (gal/capita/day)	55.0	42.5	42.5	42.5
Single-family (gal/hh/day)	20.0	18.0	18.0	18.0
Multi-family (gal/hh/day)	10.0	9.0	9.0	9.0
High-income Communities				
Population (gal/capita/day)	55.0	42.5	42.5	42.5
Single-family (gal/hh/day)	30.0	27.0	27.0	27.0
Multi-family (gal/hh/day)	10.0	9.0	9.0	9.0

Seasonal Domestic, Use All Units	1980	1990	2000	2020
Low-income Communities				
Population (gal/capita/day)	2.0	2.0	2.0	2.0
Single-family (gal/hh/day)	7.5	7.5	7.5	7.5
Multi-family (gal/hh/day)	4.0	4.0	4.0	4.0
Middle-income Communities				
Population (gal/capita/day)	2.0	2.0	2.0	2.0
Single-family (gal/hh/day)	15.0	15.0	15.0	15.0
Multi-family (gal/hh/day)	4.0	4.0	4.0	4.0
High-income Communities				
Population (gal/capita/day)	2.0	2.0	2.0	2.0
Single-family (gal/hh/day)	30.0	30.0	30.0	30.0
Multi-family (gal/hh/day)	4.0	4.0	4.0	4.0

Source: Arthur D. Little, Inc.

BASE DEMAND ESTIMATES OF DOMESTIC WATER USE

Using the water use factors described in the previous section, domestic water use projections associated with the University of Massachusetts/Amherst control forecast were derived and are presented in Tables 25 and 26, together with the basic population and household projections upon which they are based.

In summary, Table 25 shows that the noninstitutional population of the 44 MDC towns is forecast to increase by about 15 percent and households by about 21 percent. Domestic water use under these assumptions is forecast to remain approximately at its 1980 levels. (A slight decline in seasonal use is registered because of the one-time seasonal adjustment for the relatively dry summer in 1980, while a slight increase is registered for nonseasonal domestic use.) For the 25 fully-supplied MDC communities, the analogous figures represent a 12 percent increase in noninstitutional population, a 19 percent increase in households, and a 4 percent reduction in domestic water use. Table 26 shows the comparable figures for the 36 non-MDC communities.

FORECAST UNCERTAINTIES AND A CAPACITY PLANNING RANGE FOR FUTURE DOMESTIC WATER USE ESTIMATES

The principal uncertainties with respect to domestic water use projections include the projections of population and household growth and the estimated changes in domestic use factors. Uncertainties about population and households are described in Appendix E, and uncertainties about use factor estimates are described in this chapter. The assessment of uncertainties and the development of a capacity planning range for water use estimates involved a four-step process:

1) The uncertainties of individual assumptions or estimates associated with water use factors and growth forecasts, were assessed, as was the likelihood of these alternative assumptions.

2) The combined impact of alternative assumptions of water use factors on water use was subjected to a sensitivity analysis, and this assessment included the impact of regional and national growth factors on water use.

3) A joint probability matrix (for 1990, 2000, 2020) of the likelihood of alternative base demand forecasts was contructed for domestic and nondomestic water use associated with different ranges of growth and use factor estimates.

Table 25. Growth Projections & Base Demand for Domestic Water Use for Current MDC Users

	1980	1990	2000	2020
Growth Projection				
Noninstitutional Population (000)	2,078	2,169	2,237	2,376
Housholds (000)	807	872	909	980
Avg Annual Water Use (MGD)	143.03	138.55	136.54	141.79
Add'l Drought Year Demands	-	2.5	2.5	2.5
Base Domestic Demand	143.03	141.05	139.04	144.29

Source: Arthur D. Little, Inc.

Table 26. Growth Projections & Base Demand for Domestic Water Use for Potential Future Users

	1980	1990	2000	2020
Activity Indicators				
Noninstitutional Population (000)	742	808	883	1,000
Households (000)	240	270	298	342
Avg Annual Water Use (MGD)	50.67	50.88	53.11	58.94
Add'l Drought Year Demands	-	2.0	2.0	2.0
Base Domestic Demand	50.67	52.88	55.11	60.94

Source: Arthur D. Little, Inc.

4) Confidence estimates of water use forecast ranges and their associated probabilities were developed, based on the calculations for individual categories developed in Step 3.

Effect of Uncertain Growth Forecasts

The estimated probabilities of alternative levels of population/housing growth and their impact on forecast domestic water use are summarized in the left-hand columns of Table 27.

Effect of Uncertain Domestic Water Use Factors

One of the major uncertainties affecting domestic use forecasts is how the existing population and households will act as water consumers during the planning period. New growth, in the more likely mid-ranges, was projected at relatively modest levels and had little effect on the overall projections of domestic consumption. The net new population/households accounted for about 15 percent of the 2020 projections.

In the development of seasonal use factors, historic data on seasonal consumption, as well as precipitation/evaporation indicators, were taken into account. Past data did not show much change in the percentage of seasonal consumption related to the whole, other than what can be explained by wet and dry periods. The disaggregated demand model assumed no change in seasonal coefficients, primarily because of historic data. Review of swimming pool data and checks with local sources revealed no current indications that swimming pools will capture a significantly greater share of the market, and although underground sprinkler systems appear to be enjoying increasing market acceptance, installers claim that such systems use less water than a conscientiously applied lawn hosing.

Alternative Swimming Pool Assumptions. Alternative possible assumptions are that swimming pools might continue to capture more of the market. A straight-line trend projected since 1958 for the Northeast Region showed that a possible 5 percent of households would have pools by 2020. For the 44 cities and towns currently served, this could add about 840 MGY to the base demand domestic use forecasts.

Other Alternative Outdoor Use Assumptions. With respect to spas, hot tubs, and sprinkler systems, future projections would be entirely conjectural, and the assumption was that these and other unknowns might change the seasonal use for 2020 by ±10 percent or ±450 MGY.

Table 27. Effect of Growth Uncertainties on Water Use Forecasts

	Impact on Water Use Forecasts	Probability of Impact
Effect of Possibly Higher Growth Factors: Massachusetts grows at about the national rate (e.g., due to high-technology success), or the nation's growth follows Census Series I forecasts.	+10% to +20%	0.075
	+6% to +10%	0.125
Effect of Most Likely Range of Growth Factors: United States grows at Census Series III and Massachusetts continues growth performance relative to other States, equivalent to last 40 years of experience.	+3% to +6%	0.15
	±3%	0.30
	-3% to -6%	0.15
Effect of Possibly Lower Growth Factors: Massachusetts grows at a very slow rate relative to the United States (e.g., due to high-technology exodus), or the nation's growth follows Census Series III forecasts.	-6% to -10%	0.125
	-10% to -20%	0.075

Alternative Housing Mix Assumptions. A final uncertainty was that the housing mix might be different from that projected in the model. The most significant, but highly unlikely impact was that all new housing units would be single-family in high-income areas with considerable lawn watering. The impact of this could be an increase in the 2020 projection of 672 MGY; alternatively, an increasing percentage of units could be multi-family or townhouse units with much more limited lawn watering and other outdoor use and a reduction in the 2020 projection of about 300 MGY.

Estimates of nonseasonal use factors, basically in-home water usage, rely on literature findings, samples of nearly 1,200 households' water consumption in the area, and analysis of past trends. The definition of per capita and per household factors in the model resulted in a simulation of 1980 domestic consumption--for the 44 cities and towns--within 4 percent of that reported. Since future household sizes are not expected to change dramatically from present levels, the per capita/per household relationships are not expected to change either--household size being a direct influence on these values. The major foreseen determinants of future consumption changes are toilet flush water, showers, dishwashers, and clothes washers. While the model is considered to include the most likely assumptions and expectations with respect to the above factors, alternative future assumptions and their impacts were also assessed.

Alternative Toilet Flushing/Showering Ratio. Because there are different assumptions about water use reduction because of low-flush toilets and low-flow showerheads, the proportions assigned to each of these uses are significant in projecting future use. Earlier literature studies indicated a higher percentage for toilet flushing (45 percent of in-home use) than the model which is based on later studies. There is virtually no support for an opposite assumption, namely, lower proportion of water for toilet flushing than in the model. However, a lower value helps bracket the projections since there are uncertainties in the future with respect to conservation savings and the relative rates at which devices may be installed. Tested for sensitivity, therefore, are assumptions that (1) toilet flushing amounts to 45 percent and showering to 15 percent of in-house water and (2) toilet flushing at 22.5 percent and showering at 40 percent. The net effect of (1) is +309 MGY for the base water use forecasts in 2020, (+4,076 MGY for toilet flushing and -3,767 MGY for showering), and for (2) the net effect is -4,244 MGY (-7,816 MGY for toilet flushing and +3,572 MGY for showering). It should be noted that assumption (2) is far less likely than assumption (1).

Alternative Low-flush Toilet Assumptions. A highly unlikely assumption is that the plumbing code will not be implemented; there will be no low-flush toilets in housin units (baseline assumes 50 percent) or low-flush toilets will not save any water (baseline assumes 30 percent). Tl impact of this is an 863 MGY addition to projections in n units and 3,241 MGY in existing housing. Alternatively, may be assumed that more existing bathrooms will be renovated and toilets replaced by 2020 than was assumed ir the model, 75 percent instead of 50 percent. The impact c this assumption would be a reduction in the 2020 projections of 1,621 MGY.

Alternative Low-flow Showerhead Assumptions. A highly unlikely assumption is that no water-saver showerheads wil be installed (baseline assumes 90 percent), or that they will not save any water. This adds to the 2020 projection of 406 MGY in new housing and 2,745 MGY in existing housing. If the replacement rate of showerheads is considered lower than the model assumes--50 percent instea of 90 percent of all housing with low-flow showerheads by 2020--the impact would be an addition of 1,220 MGY to the 2020 projections.

Alternative Dishwasher Assumptions. Alternative assumptions with respect to automatic dishwashers and thei impacts on the 2020 projections could be:

- There are no water savings from new dishwashers over the old units (baseline assumes 15 percent). This adds 257 MGY to the projections, but others are forecasting continued improvements in water- and energy-using efficiencies of these appliances which could reduce future water use by 275 MGY if efficiencies were to be improved by only 5 percent on average.

- There are no savings from new dishwashers and dishwashing uses 10 percent more water than washing in the sink (baseline assumes no difference). The effect of this is an additional 559 MGY to the 2020 projections. Alternatively, manufacturers claim that they save 10 percent of the water otherwise used to wash dishes by hand; and if this were true, it would reduce forecasts by 559 MGY by 2020.

- Only 25 percent of replacement dishwashers (rather than 75 percent) will be water-saving models. This adds 324 MGY to the 2020 projections. Alternatively, if all new dishwashers were to conform to currently evolving standards, it could reduce future water use by about 160 MGY.

Alternative Clothes Washer Assumptions. An alternative assumption for clothes washers could be no savings in new models (baseline assumes 20 percent), but there is a higher unlikely assumption in the face of rising concerns for saving energy, hot water and water generally. The effect of such an alternative assumption is an addition of 1,127 MGY to the base demand projections. Alternatively, further increases in water use efficiencies on the order of 5 percent would reduce future water use by 282 MGY.

Other Nonseasonal Unknowns. Other water-using or water-saving devices may be introduced in the study period which have not been foreseen above. With the breadth and range of the model assumptions and alternative futures, however, it is most likely that unforeseen impacts should be no greater than ±5 percent of nonseasonal consumption. This amounts to ±2,157 MGY.

Table 28 summarizes the analysis of uncertainty and sensitivities and outlines alternative assumptions on water use factors to those in the model: assuming little or no impact because of water-saving devices, fixtures, or appliances on the one hand, to continued market penetration rates or improvements in efficiencies and technologies on the other. The right-hand column of the table indicates the probability rating assigned to the alternative assumptions from highly unlikely, 3; unlikely, 2; to possible, 1. Although the assumptions and impacts are not necessarily additive and there are synergistic effects not described in the simplified analysis, the system provides some basis for judgment about the uncertainties of the projections.

Table 29 summarizes, by the three probability ranges, the MGY and percent values relative to the base demand forecasts of domestic water use. The assumptions and analysis suggest a range (+7 to -5 percent) for possible uncertainties which may impact the projections. In the more unlikely range, the analysis suggests an additional +5 to -7 percent potential adjustment to the projections. If the assumptions rated as unlikely were down-scaled, they would be considered far more probable. For example, if it were assumed that assumptions rated as 2 in probable terms were halved, then their impacts would be much closer to possible (e.g., within the 85 percent range). The net result of this assessment of use factor uncertainties is that there is about a 65 percent likelihood that overall domestic use factors will be within ±6 percent of the base estimate in 2020, and that there is about an 85 percent likelihood that overall domestic use factors will be within ±10 percent of the base estimates.

Table 28. Alternative Assumptions About Domestic Use Factors and Impacts on Domestic Water Use Estimates

Assumptions	Impacts: Changes to 2020 Projections MGY Base Estimate	Probability Range
Seasonal Use		
More swimming pools	+840	1
Spas, hot tubs, other	±456	1
More or less SF homes w/lawns	±672	2
Nonseasonal Use		
45/15 Toilet-shower ratio	+309	2
22/40 Toilet-shower ratio	-4,244	3
No-savings toilets		
- Existing housing	+3,241	3
- New housing	+863	3
75% Low-flush toilets	-1,621	2
No-Savings showerheads		
- Existing housing	+2,745	3
- New housing	+406	3
50% Showerheads, existing housing	+1,220	2
No-savings dishwashers	+257	2
Continued improvement in water use efficiencies of dishwashers	-275	2
No-savings DWS use +10% compared to hand	+559	3
Low water use dishwashers use -10% compared to hand	-559	2
25% replace w/saver DWS	+324	2
100% replace w/saver DWS	-160	3
No-savings, clothes washers	+1,127	3
5% further increase in clothes Washer Efficiencies	-450	2
Unknowns	±2,157	1

Notes:

(1) The possibles (1 ratings) reflect some feeling that swimming pools and other outdoor type uses may continue to make inroads over and above the model assumptions. Also adding to the possibles is a conservative rating that there are unknowns not specified even in the assumptions in the model or in the alternative futures that something else might affect seasonal and nonseasonal consumption.

(2) The unlikelies (2 ratings) are not beyond the realm of possibility, but seem improbable in terms of current judgment.

(3) The extremely unlikely (3 ratings) tend to be "worst case" scenarios. Nothing works--not conservation, not devices, not the desire to reduce utility bills. The 3 ratings tend to describe a status quo before the plumbing code, before manufacturers began introducing water savers, and before people began to become aware of the costs of hot water, water, and conservation of resources in general.

e 28. **Alternative Assumptions About Domestic Use Factors and Impacts on Domestic Water Use Estimates**

Assumptions	Impacts Changes to 2020 Projections MGY Base Estimate	Probability Range
Seasonal Use		
More swimming pools	+840	1
Spas, hot tubs, other	±456	1
More or less SF homes w/lawns	±672	2
Nonseasonal Use		
45/15 Toilet-shower ratio	+309	2
22/40 Toilet-shower ratio	-4,244	3
No-savings toilets		
- Existing housing	+3,241	3
- New housing	+863	3
75% Low-flush toilets	-1,621	2
No-Savings showerheads		
- Existing housing	+2,745	3
- New housing	+406	3
50% Showerheads, existing housing	+1,220	2
No-savings dishwashers	+257	2
Continued improvement in water use efficiencies of dishwashers	-275	2
No-savings DWS use +10% compared to hand	+559	3
Low water use dishwashers use -10% compared to hand	-559	2
25% replace w/saver DWS	+324	2
100% replace w/saver DWS	-160	3
No-savings, clothes washers	+1,127	3
5% further increase in clothes Washer Efficiencies	-450	2
Unknowns	±2,157	1

Notes:

(1) The possibles (1 ratings) reflect some feeling that swimming pools and other outdoor type uses may continue to make inroads over and above the model assumptions. Also adding to the possibles is a conservative rating that there are unknowns not specified even in the assumptions in the model or in the alternative futures that something else might affect seasonal and nonseasonal consumption.

(2) The unlikelies (2 ratings) are not beyond the realm of possibility, but seem improbable in terms of current judgment.

(3) The extremely unlikely (3 ratings) tend to be "worst case" scenarios. Nothing works--not conservation, not devices, not the desire to reduce utility bills. The 3 ratings tend to describe a status quo before the plumbing code, before manufacturers began introducing water savers, and before people began to become aware of the costs of hot water, water, and conservation of resources in general.

Alternative Clothes Washer Assumptions. An alternative assumption for clothes washers could be no savings in new models (baseline assumes 20 percent), but there is a higher unlikely assumption in the face of rising concerns for saving energy, hot water and water generally. The effect of such an alternative assumption is an addition of 1,127 MGY to the base demand projections. Alternatively, further increases in water use efficiencies on the order of 5 percent would reduce future water use by 282 MGY.

Other Nonseasonal Unknowns. Other water-using or water-saving devices may be introduced in the study period which have not been foreseen above. With the breadth and range of the model assumptions and alternative futures, however, it is most likely that unforeseen impacts should be no greater than ±5 percent of nonseasonal consumption. This amounts to ±2,157 MGY.

Table 28 summarizes the analysis of uncertainty and sensitivities and outlines alternative assumptions on water use factors to those in the model: assuming little or no impact because of water-saving devices, fixtures, or appliances on the one hand, to continued market penetration rates or improvements in efficiencies and technologies on the other. The right-hand column of the table indicates the probability rating assigned to the alternative assumptions from highly unlikely, 3; unlikely, 2; to possible, 1. Although the assumptions and impacts are not necessarily additive and there are synergistic effects not described in the simplified analysis, the system provides some basis for judgment about the uncertainties of the projections.

Table 29 summarizes, by the three probability ranges, the MGY and percent values relative to the base demand forecasts of domestic water use. The assumptions and analysis suggest a range (+7 to -5 percent) for possible uncertainties which may impact the projections. In the more unlikely range, the analysis suggests an additional +5 to -7 percent potential adjustment to the projections. If the assumptions rated as unlikely were down-scaled, they would be considered far more probable. For example, if it were assumed that assumptions rated as 2 in probable terms were halved, then their impacts would be much closer to possible (e.g., within the 85 percent range). The net result of this assessment of use factor uncertainties is that there is about a 65 percent likelihood that overall domestic use factors will be within ±6 percent of the base estimate in 2020, and that there is about an 85 percent likelihood that overall domestic use factors will be within ±10 percent of the base estimates.

29. Effect of Use Factor Uncertainties on Water Use in 2020

: of Growth Factor :ainties on Water Use in 2020:	Impact on Water Use Forecasts	Probability of Impacts	Effect of Possibly Higher Use Factors: Code & Appliance Standards Not Generally Followed; Adoption of Unforeseen Water-intensive Practices		Effect of Most Likely Range of Use Factors: Plumbing Code & Appliance Standards Followed; No Further Changes in Use Factors		Effect of Possibly Lower Use Factors: Standards Tightened, Efficiencies Improved	
	→	→	+10 to +20%	+6 to 10%	+3% to +6%	±3%	-3% to -6%	-6% to -10%	-10% to -20%
f Possibly Higher actors: Massa- grows about the rate (e.g., due to hnology success) or growth follows eries I forecasts.	+10% to +20%	0.075	21 to 44 0.0038	17 to 30 0.0075	13 to 26 0.0056	7 to 23 0.0187	4 to 17 0.0150	0 to 14 0.0075	-10 to +10 0.0056
	+6% to +10%	0.125	17 to 30 0.0038	12 to 21 0.0125	9 to 17 0.0250	3 to 13 0.0313	0 to 7 0.0250	-7 to +4 0.0124	-14 to 0 0.0094
f Most Likely Range h Factors: United rows at Census Series assachusetts s growth performance to other equivalent to last of experience.	+3% to +6%	0.15	13 to 27 0.0113	9 to 17 0.0150	6 to 12 0.0300	0 to 9 0.0375	-3 to +3 0.0300	-7 to 0 0.0150	-17 to -4 0.0113
	±3%	0.30	7 to 23 0.0225	3 to 13 0.0300	0 to 9 0.0600	-6 to +6 0.0750	-9 to 0 0.0600	-13 to -3 0.300	-23 to -7 0.0225
	-3% to -6%	0.15	4 to 17 0.0113	0 to 7 0.0150	-3 to +3 0.0300	-9 to 0 0.0375	-12 to -6 0.0300	-16 to -9 0.0150	-26 to -13 0.0113
f Possibly Lower actors: Massa- grows at a very e relative to ted States (e.g., high-technology , or nation's growth Census Series ecasts.	-6% to -10%	0.125	0 to 14 0.0094	-4 to +4 0.0125	-7 to 0 0.0250	-13 to -3 0.0313	-16 to -9 0.0250	-20 to -12 0.0125	-30 to -13 0.0094
	-10% to -20%	0.075	-10 to +10 0.0056	-14 to 0 0.0075	-17 to -4 0.0150	-23 to -7 0.0187	-26 to -13 0.0150	-30 to -17 0.0075	-46 to -23 0.0056

±10% contour ±15% contour ±20% contour

Σ probabilities within ±10% contour = 0.691
Σ probabilities within ±15% contour = 0.855
Σ probabilities within ±20% contour = 0.945

KEY
% Range of Impact
Estimated Probability

Combined Effect of Growth and Use Factor Uncertainties

As noted previously, the two major uncertainties affecting domestic water use factors are the population/household growth factors discussed in Appendix E, and the domestic water use factor uncertainties described above. If these two areas of uncertainty are assumed to be unrelated, and if it is assumed they can be translated into joint probability estimates, it is possible to estimate the potential impact of both of these uncertainties separately on domestic water use forecasts and then to estimate the likelihood of different ranges of forecast water use due to the combined uncertainties.

Table 29 shows estimates of the combined probabilities of variation due to both factors for 2020 and map out the contours and likelihoods associated with different water use ranges.

Based on an analysis of Table 29 and similar matrices for other years, and based on confidence levels of 95, 90, and 85 percent for 1990, 2000, and 2020, respectively, the planning ranges for domestic water use in the 44 communities in these three years would be ±13 MGD in 1990, ±18 MGD in 2000, and ±21 MGD in 2020.

Chapter 3.
Nondomestic Water Use

INTRODUCTION AND SUMMARY

The purpose of this chapter is to describe:

- the components of nondomestic water use (sanitary, process, cooling);
- the formulation of the nondomestic water use equations including per employee, per resident, per customer, and per output use factors for different industries;
- the projections of employment/output and associated use factors that were used to forecast nondomestic water use; and
- the uncertainties in the nondomestic water use forecasts that are associated with growth and use factor estimates.

Nondomestic water use includes all metered water not used in homes and apartment buildings. It includes water used by industries, as well as water used in hospitals, universities, and other institutions; office and commercial buildings; golf courses; nurseries; etc. Five different sources were used in making the nondomestic water use estimates and forecasts:

1) a statistical analysis of past nondomestic water use in the MDC communities--particularly the water use by major users;
2) case studies of individual users, including interviews with more than 250 of the approximately 400 nondomestic users of more than 10 million gallons of water per year (MGY) in the service area;
3) the Censuses of Water Use by Manufacturers and other studies and analyses available in the literature;
4) interviews with water department superintendents, cooling system and equipment manufacturers, and plumbing suppliers; and
5) an assessment of changing water-using technologies, standards, regulations, and practices.

For the MDC service area, 1980 nondomestic water use categories were estimated to equal 126.1 MGD (50.8 MGD of sanitary use, 28.8 MGD of process use, 39.7 MGD of cooling and other uses, 5.5 MGD for special uses, and 1.3 MGD for

intertown transfers). About 40 percent of this nondomestic water use occurred in Boston and another 30 percent was concentrated in Everett, Waltham, Chicopee, Cambridge, and Worcester. About one-half of this use was industrial (90 percent process and cooling) and about one-half was commercial/institutional (80 percent sanitary). More than one-half of all nondomestic use was accounted for by the approximately 400 major users of more than 10 MGY.

Employment was forecast to increase by about 45 percent between 1980 and 2020 and institutional population by 15 percent, with output in many manufacturing industries more than doubling. With various sanitary use factors estimated to decline by 10 to 20 percent, as a result of the newly adopted plumbing codes and appliance standards, nondomestic sanitary use was forecast to grow very slowly over the next 40 years in the 44 MDC communities. With few anticipated changes in process and cooling use factors and moderate improvements in cooling use efficiencies of 10 percent by 2020, nondomestic process/cooling use was forecast to grow substantially over the next 40 years in the 44 MDC communities (from 68.5 MGD in 1980 to 100.4 MGD in 2020). Overall, nondomestic water use was forecast to increase from 126.1 MGD in 1980 to 164.9 MGD in 2020 in the current MDC service area and from 22.4 MGD in 1980 to 32.2 MGD in 2020 in the 36 potential future user communities.

The nondomestic water use uncertainties associated with growth and use factor estimates were studied. A range of ±26 MGD around the 2020 nondomestic water use forecast of 164.9 MGD for the 44 MDC communities incorporated an estimated 85 percent of these uncertainties (±5 MGD around the 2020 forecast of 32.2 MGD for the 36 potential future user communities). Table 30 summarizes the key factors influencing nondomestic water use.

COMPONENTS OF NONDOMESTIC WATER USE

In this analysis, nondomestic water use, which is about one-half of metered use and one-third of total use in the MDC communities, was categorized in terms of the volume of consumption of users, the categories of users, and the types of water use. The distribution of nondomestic water use by major categories is summarized for the 44 MDC communities in Table 31.

MAJOR AND MINOR WATER USERS

Nondomestic water users are defined as either major users of at least 10 million gallons per year or minor users of less than 10 million gallons per year. There are about 400 major nondomestic users in the MDC communities, and they accounted for about 66 MGD (including intertown transfers and users supplied directly by the MDC), or 55 percent of

Table 30. Nondomestic Water Use Estimates and Forecasts

Nondomestic Water Use Component	1980 Nondomestic Use (44 MDC Communities)	Estimated 1980 Use Factor	Estimated Change in Activity 1980-2020	Estimated Change in Use Factors 1980-2020
Sanitary use	50.8	7,000 gal/yr/employee 32,850 gal/yr/institutional resident 8,000 gal/yr employee for other, but function of regional population	+45% +16% +16%	Decline of approximately 10-15% due primarily to plumbing code requirements
Process use	28.0	Specific to each major user and each industry as function of output	Varies by industry but averages even 200%	No change in use factors but changes dampened by 25-50% due to improved efficiencies and economies of scale
Cooling and miscellaneous	39.7	Specific to each major user and each industry as function of both output (75%) and employment (25%)	Varies by industry but output growth averaged over 100% and employment about 8% in manufacturing and nonmanufacturing	10% reduction in use factor with additional dampening of 50% due to improved efficiencies and economies of scale
Special uses and transfers	6.8	NA		
	126.2			

	1980 Estimates		1990 Forecasts		2000 Forecasts		2020 Forecasts	
	44 MDC (MGD)	36 Non-MDC (MGD)	44 MDC (MGD)	36 Non-MDC (MGD)	44 MDC (MGD)	36 Non-MDC (MGD)	44 MDC (MGD)	36 Non-MDC (MGD)
Base non-domestic water use forecast (including meter replacement adjustment)	126.1	19.4	136.9	21.3	14.49	23.7	164.9	29.7
Ranges for incorporating estimated uncertainties								
85% of uncertainties							±26	
90% of uncertainties					±25			
95% of uncertainties			±11					

Source: Arthur D. Little, Inc.

Table 31. Components of Nondomestic Water Use for Current Users

	Sanitary Use	Process/ Cooling Use	Total Use
Industrial Users			
Major Users >10 MGY	1.8	34.1	35.9
Minor Users <10 MGY	2.9	22.8	25.7
Subtotal All Industrial Users	4.7	56.9	61.6
Commercial/Institutional Users			
Major Users >10 MGY	21.1	5.4	26.5
Minor Users <10 MGY	25.0	6.2	31.2
Subtotal All Commercial/ Institutional Users	46.1	11.6	57.7
Total Nondomestic Use	50.8 MGD[2]	68.5 MGD	119.3 MGD

[1]Excludes intertown transfers (1.3 MGD) and special users (5.5 MGD) supplied directly by the MDC.

[2]Throughout this report, MGD is based on 366 days per year in leap years and 365 days per year in other years.

Source: Arthur D. Little, Inc.

- total nondomestic water use in these communities in 1980. Of these major users, the 60 largest, each which use more than 100 million gallons of water per year, accounted for 39 MGD or 32 percent of the total nondomestic water use. The 176 users of 30 million gallons or more per year accounted for almost one-half of nondomestic use (56 MGD).

The 181 major industrial water users accounted for about 35 MGD, or about 60 percent of the total industrial water use in the MDC communities in 1980, and about 40 percent of industrial employment. The 218 major commercial/institutional water users accounted for about 28 MGD, or 46 percent of total commercial/institutional water use in the MDC communities in 1980, and about 32 percent of nonmanufacturing employment. Sales to and between towns accounted for the remaining 3 MGD of water use by major users.

INDUSTRIAL AND COMMERCIAL/INSTITUTIONAL WATER USERS

Nondomestic water users can also be categorized by type of user. This categorization of users allows projections of future water demand to reflect changes in the mix of activities and facilities. Users are divided into two general categories (industrial and commercial/institutional) and further into 21 types of industrial users (19 manufacturing SICs, laundries, and electric power plants) and nine types of commercial/ institutional users (e.g., hospitals, offices).

Industrial water users are defined as all manufacturing establishments, plus laundries and electric power plants. These industrial users accounted for approximately 61.5 MGD of water use in the 44 MDC communities in 1980 -- or about 52 percent of nondomestic use (excluding intertown transfers and special users) reported. Because of the wide range of use practices by major industrial users, each was considered to have unique water use practices and components. For minor users, because of significantly different water use practices in different manufacturing industries, each of 21 categories of minor users was considered to represent a group of water users having water use practices and components which generally differed from those of other categories.

Commercial/institutional water users are defined as all nonmanufacturing establishments, excluding electric power plants and commercial laundries, but including hospitals, universities, nursing homes and other institutions, hotels/motels, restaurants, and other commercial or office establishments. Parks/recreational facilities, schools, other government facilities, and sales to and between other towns (amounting to an estimated 3.3 MGD in 1980) were considered to be commercial/institutional users to assure that

they would be forecast separately. The commercial/institutional users accounted for approximately 57.8 MGD of water use in the 44 MDC communities in 1980 -- or about 48 percent of nondomestic use (excluding intertown transfers and special users) reported. Because of the range of use practices by major commercial/institutional users, each major user is considered to have unique water use practices and components. Although there are also a wide range of use practices among minor commercial/institutional users, almost all of their water use is sanitary, and they were not further categorized.

Estimated Allocation of Water Use to Major and Minor Industrial and Commercial/Institutional Users

The number of major water users, their employment, and reported water use, as classified by general two-digit SIC code, is shown in Table 32. The employment and estimated allocation of minor industrial user water use for these minor users is also shown in Table 32. These allocations of minor user water use are based on estimates of the relative water use per employee for minor industrial and commercial/institutional users, as determined from user interviews, the 1973 and 1978 U.S. Census of Water Use in Manufacturing, and the literature. The number of major commercial/institutional water users, their employment, and reported water use by category are also shown in Table 32, along with the employment and allocated water use of minor commercial/institutional users.

CASE STUDIES AND LITERATURE FINDINGS

Literature Findings on Industrial Water Users

The most important source of information on industrial nondomestic water use factors outside the MDC district is the U.S. Census of Water Use by Manufacturers in 1973 and 1978. When these Census data and other special studies were compared with information on nondomestic use within the MDC service area, it was apparent that the average water use per employee factors for individual manufacturing industries in the MDC communities were slightly below the national averages. Because of a higher concentration of less water-intensive industries in this area, the overall industrial use per employee was about 60 percent lower in the Boston metropolitan area than in the United States. Table 33 shows the average total water use per employee by industry for the United States and Massachusetts.

For users of more than 20 MGY nationwide, the components of water use are illustrated in Table 34.

Table 32. Classification of Industrial and Commercial/Institutional Water Users and 1980 Employment and Water Use (current users)

		Major Users				Minor Users	
	Industrial Users	# in 1980	Estimated Employment in 1980	Reported Use in 1980 (MGY)	Gallons Per Employee	Employment in 1980	Estimated Water Use in 1980 (MGY)
20	Food & Kindred Prod.	29	9,585	1,848.3	192,800	4,498	530
22	Textile Mill Prod.	4	618	254.3	411,500	2,983	163
23	Apparel & Other Textile Prod.	1	120	10.0	83,300	12,331	917
24	Lumber & Wood Prod.	1	35	12.7	362,900	855	117
25	Furniture & Fixtures	0	-	-	-	2,987	161
26	Paper & Allied Prod.	4	3,543	400.2	113,000	7,143	443
27	Printing & Publishing	3	3,575	122.9	34,400	16,533	1,130
28	Chemicals & Allied Prod.	10	2,924	1,011.3	345,800	6,394	863
29	Petroleum & Coal Prod.	1	157	75.7	482,200	639	129
30	Rubber & Plastic Prod.	16	6,130	775.0	126,400	7,016	594
31	Leather & Leather Prod.	9	529	156.3	295,500	5,852	219
32	Stone, Clay & Glass Prod.	2	3,808	394.4	103,600	2,955	668
33	Primary Metal Industries	11	2,521	468.5	5,800	2,419	170
34	Fabricated Metal Prod.	19	6,334	743.7	117,400	17,088	1,232
35	Machinery except Electrical	13	7,929	777.3	98,000	30,661	1,029
36	Electrical & Electronic Eq.	23	17,535	1,320.9	75,300	18,387	471
37	Transportation Equip.	5	8,084	739.2	91,400	4,008	176
38	Instruments & Related Prod.	13	17,821	1,203.0	73,100	11,142	423
39	Misc. Manufacturing	4	3,300	679.8	206,000	2,434	261
49	Electric Power Plants	4	1,026	1,559.8	1,520,300	0	0
72	Commercial Laundries	9	988	223.3	225,000	NA	200
	Subtotal, Industrial Users	181	96,562	12,874.5	133,300	156,235	9,896
	Institutional/Commercial Users						
	Hospitals	47	67,326	2,209.9	32,800		
	Universities/Boarding Schools	22	36,150	2,577.5	71,300		
	Other Institutions & Nursing Homes	12	9,869	489.2	49,600		
	Hotels	26	7,845	747.6	95,300		
	Restaurants	6	1,300	85.8	66,000		
	Trade	10	7,820	264.5	33,800		
	Offices	53	136,709	1,390.2	10,200		
	Other Commercial	22	13,701	891.1	65,000		
	Public	20	30,401	1,580.0	52,000		
	Subtotal, Commercial/Institutional Users	218	311,121	10,235.8	32,900	692,747	9,924
	Intertown Transfers	10	NA	1,222.5	NA	0	0
	TOTAL, NONDOMESTIC USE	409	407,683	24,333		848,982	19,820

Source: Arthur D. Little, Inc.

Table 33. Water Use Per Employee by Industry Group, 1973-1978

SIC Code	Industry Group	National Total Water Use per Employee*		Massachusetts Total Water Use per Employee*
		1973	1978	1973
	All Industries	2,121,000	1,958,000	822,000
20	Food & Kindred Products	1,165,000	1,116,000	1,146,000
21	Tobacco Manufacturing	122,000	108,000	**
22	Textile Mill Products	389,000	416,000	556,000
24	Lumber & Wood Products	2,051,000	2,001,000	***
25	Furniture & Fixtures	125,000	493,000	***
26	Paper & Allied Products	8,625,000	8,347,000	5,602,000
28	Chemicals & Allied Products	7,691,000	7,994,000	1,727,000
29	Petroleum & Coal Products	12,456,000	12,063,000	***
30	Rubber & Miscellaneous Plastic Prod.	631,000	729,000	761,000
31	Leather & Leather Products	421,000	559,000	895,000
32	Stone, Clay & Glass Products	901,000	927,000	465,000
33	Primary Metal Industries	6,004,000	4,630,000	462,000
34	Fabricated Metals	234,000	229,000	634,000
35	Machinery, except Electrical	245,000	251,000	550,000
36	Electric & Electronic Equipment	118,000	150,000	107,000
37	Transportation Equipment	199,000	192,000	174,000
38	Instruments & Related Products	186,000	159,000	398,000
39	Misc. Manufacturing Industries	203,000	160,000	215,000

*Represents employees in 1972 in establishments consuming 20 MG of water or more.
**Not a significant water-using industry group in Massachusetts.
***Figures not disclosed.

Source: Arthur D. Little, Inc., from Census of Water Use by Manufacturers, 1972, "SR4-40 Water Use in Manufacturing." and U.S. Census of Manufactures, 1978.

Table 34. Water Intake by Purpose for Industry Groups

SIC Industry Code	% Sanitary	% Processing	% Cooling[1]	% Other	% All Users
20	4	36	50	10	100
22	3	68	20	9	100
24	3	41	42	14	100
25	10	20	67	3	100
26	1	63	34	2	100
28	1	21	76	2	100
29	1	8	87	4	100
30	13	15	70	2	100
31	25	56	12	7	100
32	3	35	58	4	100
33	1	29	68	2	100
34	21	41	35	3	100
35	17	23	57	3	100
36	19	44	33	4	100
37	15	32	37	16	100
38	7	43	48	2	100
39	16	35	48	1	100
Total	3	32	62	3	100

[1]Includes steam electric generation, air conditioning, boiler feed, and other.

Source: 1978 Census of Manufactures and Water Use in Manufacturing.

Major User Surveys and Case Studies

Water use and employment data on the approximately 400 major users and results of the approximately 250 major user surveys indicated a considerable range in water use practices and water use per employee (see Appendix D-2). The range ran from more than 1 million gallons per employee per year at electric power plants, several electroplating facilities, chemical plants, beverage companies, and food processors, to about 10,000 gallons per employee per year at many of the major office buildings. There was much greater consistency in the water use per employee within categories of users. This was true even where water use was largely process/cooling and related to facilities, equipment, or output (e.g., at manufacturing plants) and where sanitary water use was largely related to use by residents or customers (e.g., at hospitals, restaurants, universities, etc.). However, there was still too much variance within manufacturing industries and some non-manufacturing categories to establish a reliable set of use factors for forecasting total nondomestic use. The user interviews indicated that water use per employee by smaller users was much more consistent within general groupings of industries and categories of nondomestic use than for individual large users.

For many categories of major nondomestic users, there were growth projections other than employment (e.g., output, resident institutional population, number of hospital beds, square footage of space) that were equal or more accurate indicators of relative water use. Since most of these projections were fairly well correlated with employment within individual user categories (with the exception of institutional residents at schools and universities), and since employment by category was the most generally available historical and projected statistic for individual communities and categories of users, a water use factor per employee was considered to be the most reasonable surrogate indicator for estimating 1980 use allocations.

Table 35 compares the water use per employee for major and minor users in the state and in the nation from the Census, with use based on user surveys within the MDC. While relative water use intensity in the MDC sample tended to parallel that in the national sample, producers in the MDC sample tended to be relatively less water-intensive (probably due to the particular categories of facilities in the MDC area).

Since many interview respondents had difficulty estimating the amount of sanitary water use separate from process/cooling use, an analysis of major users having primarily employee-related sanitary use was conducted to

Table 35. Industrial Water Use Factors from the Census and the User Survey

SIC Code	Users of More Than 20 MGY (gallons of public-supplied water per employee per year) U.S. Average 1978[1]	MDC User Survey Results	Users of Less Than 20 MGY (gallons of all water per employee per year) U.S. Average 1978[1]	MDC User Survey Results[2]
20	348,000	209,000	105,000	100,000
22	224,000	1,095,000	50,000	84,000
23	NA	NA	NA	83,000
24	521,000	NA	114,000	NA
25	462,000	NA	40,000	363,000
26	1,276,000	113,000	58,000	NA
27	NA	42,000	NA	14,000
28	1,344,000	346,000	112,000	NA
29	2,383,000	482,000	160,000	NA
30	291,000	165,000	97,000	51,000
32	189,000	104,000	128,000	NA
33	233,000	295,000	60,000	66,000
34	161,000	116,000	61,000	124,000
35	129,000	170,000	51,000	11,000
36	117,000	91,000	36,000	33,000
37	136,000	91,000	48,000	NA
38	61,000	75,000	42,000	41,000
39	110,000	283,000	66,000	17,000
Electric Utilities	NA	1,520,000	NA	NA
Laundries	NA	410,000	NA	134,000
All Industries (Mass. Ave. 235,000)	351,000	∿153,000	53,000	∿50,000

[1] U.S. Census of Manufactures, 1978.

[2] The surveys of small users focused primarily on these between 10 and 20 MGY and consisted of very small samples in some industries.

Source: Arthur D. Little, Inc.

determine a basic employee-related sanitary use factor for all users. Although the presence of a cafeteria or restaurant facilities appeared to have a significant impact on this use factor, interviews with managers or engineers at approximately 30 major office buildings and corporate headquarters indicated that 5,000 gallons per employee per year was the minimum estimated sanitary use per employee in 1980. Sanitary water use factors as high as 8,000 to 9,000 gallons per employee were frequently reported at locations that had cafeterias.

SANITARY, PROCESS, AND COOLING USES

Nondomestic water use can also be categorized by type of water use. This permits forecasts of components of water use separately as a function of different variables (e.g., employment, institutional population, customers, industrial output, facilities), and the specific changes taking place in technologies and practices (e.g., low-flush toilets now being required, closed-cycle cooling systems). Water use is divided into three major components -- sanitary (for employees, residents, customers), process, and cooling, which includes other relatively insignificant nonsanitary uses, such as outdoor use.

Sanitary Water Use by Nondomestic Users

Nondomestic sanitary use overall represented about 50.8 MGD in the MDC service area in 1980 and accounted for about 43 percent of all nondomestic use. Because of the limited amounts of process and cooling use of water by commercial/institutional users, 91 percent of sanitary use was effected by commercial/institutional users, while industrial users accounted for only 9 percent. Based on user surveys and reviews of sanitary water use practices, it was estimated that sanitary use accounted for less than 10 percent of industrial use and was largely employee-related. For commercial/institutional users, sanitary water use was estimated to account for 80 percent of water use and was, in part, employee-related; in part, resident-related; and, in part, customer-related. (Customers include all users who are neither employees nor permanent residents, such as day students, restaurant or hotel customers, hospital patients, etc.)

For employee-related sanitary use at industrial establishments, an estimate of an average of 7,000 gallons per employee per year (about 20 gal/emp/day or 30 gal/emp/working day) was used and this indicated that 5 to 10 percent of major-user use was in the employee-related sanitary category and that 10 to 15 percent of minor-user use was in the employee-related sanitary category use (a total of about 4.7 MGD in the 44 MDC communities). These

- estimates were generally consistent with those reported in the major user interviews.

For commercial/institutional users, employee-related sanitary use was estimated to equal 17.5 MGD for the 44 MDC communities in 1980. Substantial additional amounts of sanitary use have been reported for institutional populations (primarily at universities, nursing homes, and State hospitals/prisons) and for user populations (hotel guests, restaurant customers, retail customers, hospital patients and visitors, etc.). For institutional populations, sanitary water use was estimated on the basis of the major user surveys. Estimated resident-related use factors adjusted to reflect full-time occupancy equalled 90 gallons per capita per day or 7.2 MGD for the 44 MDC communities in 1980. The balance of reported sanitary use at commercial/institutional facilities equalled 21.4 MGD and was assumed to be customer-related sanitary water use. For commercial/institutional users, these calculations indicated that 30 percent of water use was employee-related sanitary use, 12 percent was resident-related sanitary use, 37 percent was customer-related sanitary use, and 20 percent was other (nonsanitary) use.

This sanitary use is sensitive to many of the same types of changes as were discussed in Chapter 2--Domestic Use, and is even more sensitive than domestic use to plumbing code revisions governing toilets and the rate of replacement of older, less water-efficient fixtures. About 65 percent of the major commercial/institutional users interviewed reported having instituted significant water-saving measures in recent years (primarily water-saving devices). There appeared to have been a reduction of about 6 percent in the water use of these major users between 1972 and 1980, despite increases in employment/ enrollment in many cases. Very few of those interviewed indicated plans for further conservation measures. However, the normal replacement of older toilets and showerheads with the more efficient ones now required by the code is likely to result in some further reduction in water use per employee, customer, or resident.

Process/Cooling Water Use by Nondomestic Users

Process/cooling water use at commercial/institutional establishments was estimated to amount to 11.6 MGD in the 44 MDC communities in 1980 and, from the major user surveys, was estimated to be more than 95 percent for cooling use (primarily for space cooling but also for equipment such as computers) and less than 5 percent for outdoor use. Process/cooling water use at industrial establishments was estimated to amount to 54.8 MGD in the 44 MDC communities in 2020.

Most process/cooling water use by nondomestic users (more than 80 percent) occurs at industrial establishments where use practices vary widely, but where both user interviews and the 1978 Census of Water Use by Manufacturers indicated that process use (where water is used in, or comes in contact with, the product) accounted for one-half of process/cooling use. This process use is particularly important in the food processing, paper, and primary metals industries where such use accounts for about one-half of process/cooling use, and in the textiles, chemicals, and fabricated metals industries where process use accounts for about one-third of process/cooling use.

Cooling use and boiler-feed also represent about one-half of the process/cooling use at industrial establishments (26.0 MGD). Although practices vary widely, only a small portion is generally used for space cooling, while a much larger portion is used for cooling equipment or products.

FORMULATION OF NONDOMESTIC WATER USE EQUATIONS

APPROACH TO MODELING OF SANITARY AND PROCESS/COOLING USE BY NONDOMESTIC WATER USERS

Nondomestic metered water use was reported by water departments in each MDC-served community. The 1980 totals have been adjusted to reflect differences in reporting procedures and other factors (see Appendix A). For the potential future users, estimates of nondomestic use were derived from the application of the domestic estimation equation and checked against major-user use and a generalized nondomestic use estimation equation. All adjusted reported nondomestic water use in each community was then allocated by the model to different major users (based on user surveys and water department data) to different categories of minor users (based on relative employment in the town and on the relative water intensity estimated for the region for each category of users) and to different types of water use (e.g., sanitary, process, cooling).

These base year components of nondomestic water use for each community were then related to a weighted average of growth projections (e.g., output, employment, institutional population), so that future estimates of nondomestic water use components could be developed as a function of altered growth projection levels, altered technologies and use practices, and planned or potential conservation efforts as estimated on the basis of the user interviews. The demand simulation model, therefore, is able to demonstrate the water use implications of a changing economic structure in the region. At the same time, the model incorporates explicit assumptions about the technology and efficiency of various water-using fixtures and appliances as they change

over time, as well as judgment about baseline changes in use practices and conservation.

EXPLANATORY EQUATIONS AND USE FACTORS FOR 1980 NONDOMESTIC WATER USE

In order to provide a solid basis for forecasting future nondomestic use, a series of use factors and an overall explanatory equation for nondomestic use were developed. These use factors and equations were used to develop an equation which reflects the causal relationships existing between different types of water use and different growth projections and adjusted-use factors for the future. They were used to fill gaps and adjust for inconsistencies in the base year 1980 data on individual major users and on overall nondomestic use in each community.

1980 Estimating Equation for Nondomestic Water Use

The equation for estimating nondomestic water use and comparing its results with estimates made by water departments and, consequently for making independent adjustments or estimates where warranted is outlined below:

- 1980 Industrial Use = Reported Major User Use[(1)] + No. gal/employee of Minor Users[(2)] + E[(3)]

(1) The water use of all users of more than 10 million gallons per year as reported by the local water department and by the major users. Reported water use was allocated to sanitary use at the rate of 7000 gal/employee/yr, based on the major users' reported employment as determined by telephone survey. The balance of reported water use was allocated to process and cooling/miscellaneous use in proportion to quantities reported in the major user surveys; or where such data were unavailable, in proportion to that reported for the user's industry classification in the national census (as reported in Table 35).

(2) No. is different for each industry, as listed in Column 2 of Table 36, and minor user employment was determined by subtracting reported major user employment in each industry from the town's total employment in each industry, as reported by the Massachusetts Department of Employment Security (DES).

(3) E was the initially unexplained nondomestic use which, for forecasting purposes, was allocated to

Table 36. Estimated 1980 Water Use Factors for Nondomestic Users (gallons per employee per year)

Activity	Annual Water Use per Employee: Major Users[1]	Minor Users[2]	All Users[3]
Industrial Users (by SIC)			
20 Food & Kindred Products	193,000	109,000	150,000
22 Textile Mill Products	412,000	50,000	100,000
23 Apparel & Other Textile Prod.	83,000	53,000	53,000
24 Lumber & Wood Products	363,000	114,000	200,000
25 Furniture & Fixtures	NA	46,000	125,000
26 Paper & Allied Products	113,000	58,000	75,000
27 Printing & Publishing	34,000	53,000	53,000
28 Chemicals & Allied Products	346,000	112,000	250,000
29 Petroleum & Coal Products	482,000	160,000	250,000
30 Rubber & Plastic Products	126,000	97,000	125,000
31 Leather & Leather Products	296,000	35,000	35,000
32 Stone, Clay & Glass Products	104,000	128,000	150,000
33 Primary Metal Industries	186,000	60,000	100,000
34 Fabricated Metal Products	117,000	61,000	75,000
35 Machinery except Electrical	98,000	51,000	60,000
36 Electrical & Electronic Equip.	75,000	36,000	50,000
37 Transportation Equipment	91,000	48,000	75,000
38 Instruments & Related Prod.	73,000	42,000	50,000
39 Misc. Manufacturing	206,000	66,000	70,000
49 Electric Power Plants	1,520,000	NA	NA
72 Commercial Laundries	225,000	NA	NA
Commercial/Institutional Users			
Hospitals	33,000		
Universities/Boarding Schools	71,000	20,000 per	25,000 per
Other Institutions & Nursing Homes	50,000	employee	employee
Hotels/Motels	95,000	plus	plus
Restaurants	66,000	32,850 per	32,850 per
Trade	34,000	institutional	institutional
Offices	10,000	resident	resident
Public	52,000		

[1] Use factors based on surveys of 399 major users of more than 10 MGY in the MDC district.
[2] Use factors based on user surveys and 1978 Census of Water Use in Manufacturing.
[3] Use factors based on user surveys and 1978 Census of Water Use in Manufacturing.

Source: Arthur D. Little, Inc.

each industry in proportion to its minor-user water use, as estimated in Equation (2).

- 1980 Commercial/Institutional Use = Reported Major User Use[(1)] + 20,000 gal/yr per minor user employee[(2)] + 32,850 gal/yr per minor user institutional resident[(3)] + E[(4)]

(1) The water use of all users of more than 10 million gallons per year as reported by the local water department and by the major users. Reported water use was allocated to employee-related sanitary use at the rate of 7,000 gal/yr per employee, to institutional resident use at the rate of 32,850 gal/yr per institutional resident, as reported in the survey, with the balance allocated to customer and other related sanitary uses.

(2) Employment at minor users was calculated by subtracting major user employment from DES-reported employment for the community. This use was allocated to employee-related sanitary use at the rate of 7,000 gal/yr per employee with the balance allocated to customer-related sanitary use and cooling/miscellaneous use in proportion to that reported by major users.

(3) Institutional population of minor users was calculated by subtracting major-user institutional population from 1980 Census reported institutional population for each town.

(4) E was the initially unexplained nondomestic use which, for forecasting purposes was allocated to minor users in proportion to their water use as estimated in (2) and (3).

Table 37 shows the adjusted reported nondomestic use for 1980, the nondomestic use as estimated by the equation cited above, and the difference unexplained as a percent of total adjusted nondomestic. The final column on the right shows the combined unexplained domestic and nondomestic use as a percentage of total metered use. For most MDC communities with significant nondomestic use, these equations resulted in a difference of less than 7 percent between 1980 nondomestic use estimated by the model and that reported to the MDC. In several communities where the model substantially overestimated nondomestic use relative to that which was reported, the domestic equation underestimated domestic use relative to that which was

Table 37 Comparison of Reported Water Use with the Estimates Derived from Generalized Equations

	1980 Adjusted Reported Metered Water Use (MGY)	1980 Adjusted Reported Nondomestic Use (MGY)	1980 Nondomestic Water Use as Estimated by Equation (MGY)	Unexplained Nondomestic Use[1] (MGY)	Unexplained Nondomestic Use[2] (Percent of Reported Nondomestic Use)	Unexplained Domestic & Nondomestic Use (Percentage of Total Metered Use)
Boston	30,678	17,628	16,424.3	(1203.7)	(-7%)	(7%)
Worcester	7,234	4,524	4,596.8	72.8	2%	11%
Cambridge	5,222	3,322	3,413.7	91.7	3%	9%
Waltham	3,390	1,959	2,549.5	590.5	30%	12%
Chicopee	3,057	1,635	1,648.5	13.5	1%	5%
Everett	2,349	1,546	1,619.1	73.1	5%	5%
Leominster	1,932	1,232	1,298.6	66.6	5%	4%
Quincy	3,213	1,145	1,161.3	16.3	1%	(4%)
Subtotal (8 largest non-domestic users)	57,075	32,991	32,711.8	(279.2)	(0.8%)	(1.1%)
Other MDC Communities (36)	39,426	11,162	13,591.0	2,429.0	21.8%	3.6%
Special Users (5)	1,119	1,119	1,119.0	0	0%	0%
TOTAL	97,620	45,271	43,421.8	2,293.8	5.1%	0.8%

[1]Unexplained use is the difference between adjusted reported use and use estimated by the explanatory equations.

Source: Arthur D. Little, Inc.

reported. These two offsetting reporting differences may, in fact, reflect inconsistencies in water department reporting practices.

EMPLOYMENT/OUTPUT PROJECTIONS

The activity levels which must be forecast to estimate future nondomestic use are:

- institutional population (at state hospitals, military installations, universities, etc., for both major users and minor users in each community);
- employment (by industry for both major and minor users in each community);
- customers or visitors (using regional population as a surrogate and indexing 1980 as 100); and
- output by industry (i.e., industrial production for both major and minor users indexed to 1980 as 100)

STATEWIDE EMPLOYMENT FORECASTS

As with population forecasts, there is a variety of forecasts available for these activities, and there is considerable uncertainty about 20- to 40-year forecasts, particularly given the recent structural shifts in the New England economy. Whether the traditional industries (e.g., food processing, textiles, apparel, chemicals) will continue to decline in New England, or whether they have now stabilized is one important question; another is the question of continued growth in high technology and service industries, including the highly competitive higher education institutions and hospitals.

The relationships between economic development, business costs, and employment opportunities and the characteristics of the region's population are complex. The University of Massachusetts/Amherst M.E.P.A. model, described in Appendix E, appears to be a reasonable representation of this dynamic. It is based, in part, on national forecasts from Data Resources, Inc. (DRI) and is tailored to the Massachusetts situation. This M.E.P.A model, which is subscribed to by other state agencies and incorporates both very current and long-term historical data, was adopted for use in this study.

The statewide employment forecasts under the mid-range control scenario for 2007 are summarized in Table 38, which also shows the extrapolation of these forecasts to 2020 (based on 2000-2007 rates of growth). These employment forecasts are generally higher than the U.S. Department of

Table 38. Employment Forecasts (in thousands)

	1980	1990	2000	2007	2020	Cumulative % Change 1980-2020	Annual % Change 1980-2020
1. Forecasts of U.S. Employment Based on U.S. Census Series II population as used in the M.E.P.A. model	90,530	105,230	116,640	124,980	142,000	56.9	1.13
2. M.E.P.A. Forecasts of Massachusetts Employment Based on U.S. Series II							
- Control Forecast	2,653	2,957	3,184	3,362	3,746	41.2	0.87
3. M.E.P.A. Employment Forecasts as Allocated to 44 Current MDC Communities							
- Control Forecast	1,257	1,427	1,532	-	1,817	44.6	0.93
4. M.E.P.A. Employment Forecasts as Allocated to 36 Non MDC Communities in the Planning Area							
- Control Forecast	313	372	412	-	487	55.6	1.11

Source: Arthur D. Little, Inc.

- Commerce (OBERS) forecasts for the state, which were heavily influenced by the severe 1974-1975 recessionary impact on Massachusetts. The M.E.P.A. forecasts indicated that employment was growing about two-thirds the national rate, a relative growth which is similar to Massachusetts' long-term historical performance, but below its performance of the last seven years, when it grew about the same rate as the United States.

ALLOCATIONS OF EMPLOYMENT GROWTH TO STUDY AREA COMMUNITIES

The estimated allocation of statewide employment growth in individual industries to individual communities was based on the community's share of growth/decline in that industry over the last 10 years, with no community permitted to have long-term growth in an industry at more than 150 percent of the statewide rate or less than 75 percent of this rate.

INDUSTRIAL OUTPUT AND INSTITUTIONAL POPULATION GROWTH

Industrial production estimates were derived from DRI's forecasts of changes in output per employee in each industry. Institutional population forecasts were developed as part of the population forecasts and were assumed to change at the same rate as regional population in all communities.

FUTURE OF NONDOMESTIC WATER USE FACTORS

The 1980 nondomestic water use in different industrial and commercial/institutional categories was divided into different water use components, so that water use factors could be forecast and linked to changes in employment, population, or output.

For industrial users, these components included:

- employee-related sanitary use;
- output-related process use; and
- cooling use related to both output and employment.

For commercial/institutional users, the components included:

- employee-related sanitary use;
- institutional resident-related sanitary use;
- customer-related sanitary use; and
- cooling use related to employees, residents, and customers.

In order to estimate future changes in nondomestic water use factors associated with each of these components, recent and anticipated changes in reported water use for individual users were evaluated on the basis of the surveys. The historical change in overall nondomestic use was also evaluated for individual categories of users. Information from the commercial/institutional conservation analyses and case studies was incorporated to estimate potential baseline impacts of altered price levels (as communities moved to full cost recovery under Proposition 2½), the impacts of likely baseline conservation measures, and the impacts of improved technology and normal replacement of equipment and facilities.

INDUSTRIAL WATER USE FACTORS

Industrial use declined substantially between 1972 and 1980 due, in large part, to the shifting industrial base. Table 39 demonstrates the degree to which the growing Massachusetts industries tend to be less water-intensive than the declining Massachusetts industries. In 1972, there were 81 industrial users of water in the MDC that used more than 50 million gallons per year and accounted for about 12,750 million gallons of publicly supplied water in 1972[1]. By 1980, there were only 60 such users and their total use had declined by almost 20 percent to 10,333 million gallons. All industrial users of more than 10 million gallons of water per year accounted for 17,290 million gallons of publicly supplied water in 1972, and this had declined by 25 percent to 12,875 million gallons by 1980. Most of this dramatic decline was due to a shifting economic base and the closure of many large water-intensive manufacturing facilities.

However, even growing industries showed declining use by major users. As shown in Table 40, water use by major users declined in every industrial category except two (where there were special circumstances). Plant closings accounted for about 15 percent of the decline in use by major users. Use by businesses which have been in operation through the decade declined by about 7 percent. In the declining (in terms of employment) industries which use the most water (food processing, leather, chemicals, rubber and plastics, paper, and primary metals), plant closures accounted for most of the decrease in water use, while use by continuing businesses remained relatively stable.

Table 39. Relative Water Use Inventory of High-Growth and Low-Growth Industries in Massachusetts

SIC		Change in Massachusetts Employment (1970-1980) No.	Change in Massachusetts Employment (1970-1980) %	Publicly Supplied Water Use per Employee (U.S. average 1978) Major Users (>20 MGY)	Publicly Supplied Water Use per Employee (U.S. average 1978) Minor Users (<20 MGY)
	Declining Industries (1970-80)				
31	Leather & Leather Products	(14,625)	(40.3)	375,000	35,000
20	Food & Kindred Products	(9,823)	(26.5)	348,000	105,000
23	Apparel	(9,443)	(19.1)	NA	NA
26	Paper & Allied Products	(6,747)	(19.3)	1,276,000	58,000
22	Textiles	(6,655)	(21.0)	224,000	50,000
30	Rubber & Misc. Plastics	(3,009)	(9.0)	291,000	97,000
25	Furniture	(1,983)	(19.6)	462,000	40,000
33	Primary Metals	(1,898)	(9.8)	233,000	60,000
28	Chemicals	(1,424)	(7.4)	1,344,000	112,000
	All Declining Industries	(55,508)		569,000	70,000
	Growing Industries (1970-80)				
35	Nonelectrical Machinery	35,967	48.7	129,000	51,000
38	Instruments	24,815	76.8	61,000	42,000
36	Electrical Machinery	18,215	19.5	117,000	36,000
34	Fabricated Metals	12,673	31.0	161,000	61,000
37	Transportation Equipment	9,834	38.4	136,000	48,000
32	Stone, Clay & Glass	1,319	11.0	189,000	128,000
	All Growth Industries	102,823		132,000	61,000
	Stable Industries				
29	Petroleum & Coal Products	751	107.2	2,383,000	160,000
24	Lumber & Wood Products	606	13.2	521,000	114,000
27	Printing & Publishing	277	0.6	NA	NA
39	Misc. Manufacturing	(839)	(3.0)	110,000	66,000
	All Stable Industries	795		1,004,000	113,000
	ALL INDUSTRIES (weighted avg.)	48,000	7.4	351,000	53,000

Source: Arthur D. Little, Inc.

Table 40. Trends in Industrial Water Use

Category of User	Completed No. in Sample[1]	1980 Water Use (MGY)	Percentage Change in Water Use 1972-1980	1980 Employment	Percentage of Use by 1980 Major Users
Food Processing	45	1,885.4	-15.0%	10,658	7.6
Textiles	7	259.0	-28.0	968	1.0
Paper & Coatings	8	408.7	-10.0	4,003	1.6
Printing	3	122.9	-23.0	3,575	0.5
Chemicals	14	1,025.1	-6.0	3,311	4.2
Rubber & Plastics	30	833.6	-52.0	6,547	3.2
Leather	15	166.3	-42.0	529	0.6
Building & Indus. Materials	3	402.8	-11.0	3,888	1.6
Primary Metals	14	468.5	-27.0	2,521	1.9
Fabricated Metals	26	798.7	-39.0	7,219	3.1
Nonelect. Mach. & Trans.	17	787.3	105.0[3]	7,929	3.2
Electrical Machinery	27	1,342.2	-32.0	18,115	5.4
Transportation Equipment	5	739.2	0.0	8,084	3.0
Miscellaneous Manu.	6	684.8	15.0[4]	3,325	2.8
Other Manufacturing[2]	19	108.2	-85.0	312	0.5
Utilities	5	1,564.8	-5.0	1,026	6.4
Laundries	13	232.3	-5.0	988	0.9
Total Manufacturing	271	13,149.1	-22.0	101,509	52.9

[1] Includes companies which were major users in 1972 and/or in 1980.

[2] Includes manufacturing SIC groups with only one major user and 1972 major users which have closed and for whom industry groupings could not be identified.

[3] Use would have declined by 9 percent, except for relocation of one major user to an MDC-supplied town and the purchase of U.S. Government facilities for general industrial use.

[4] Includes two industrial parks whose 1972 use may be underestimated.

Source: Arthur D. Little, Inc.

- Water use declines by major users in growing industries are generally attributable to the effects of conservation. Widespread conservation efforts in the fabricated metals, instruments, and electrical machinery industries resulted in declines in water use of 37, 27, and 14 percent, respectively, by major users continuing in business. Use by transportation, equipment, and nonelectrical machinery producers already in business was stable, despite industry growth; the increase in the machinery industry's use was due to two large new users. These declines in water use were due principally to shifts in the goods produced or processes employed and to major improvements in water and energy use efficiency (prompted by effluent regulations, energy prices, and water or sewer costs).

  Interview updates conducted with about 75 industrial users in 1982 indicated that some further shifts in water use had occurred, but that most major energy- and water-saving improvements considered feasible had been put in place, and that further changes in water use were occurring primarily as the result of altered employment and output levels or altered product lines.

In addition to interviews with major industrial users, water conservation case studies of individual users were conducted as part of the demand management analysis (Task 3). These and other case studies confirmed that most major water use efficiency improvements have already been put in place. However, some further water use efficiency improvements are expected by industrial users as facilities continue to be modernized over the next 40 years.

Future Industrial Sanitary Use Factors

For industrial sanitary use, it was estimated that 10 percent of all users had implemented water conservation efforts oriented to sanitary devices (low-flow toilets or flow restrictors) and 27 percent of the major industrial users (out of a sample of 89) had indicated implementation of some sanitary conservation program by 1982. The state plumbing code requires all new and replaced toilets or flushometers to be of the low-flow type (a maximum of 1.5 gallons per flush for urinals and 3.5 gallons per flush for toilets). Since toilet flushing was estimated to account for about 75 percent of employee-related sanitary use at a current average of about 4.5 gallons per flush, normal replacement of existing toilet fixtures and construction of new facilities will have a substantial impact on this use over the long term. These forecasts assume that 60 percent of all industrial toilets will be of the low-flow type by 2020 (at an average of 2.5 gallons per flush compared to the 4.5 gallons per flush estimated for 1980), and that the

industrial sanitary use factor will therefore decline from the current 20 gallons per employee per day to 17 gallons per employee per day by 2020. No further change in other sanitary use practices or technologies (e.g., washing, drinking, cafeteria) were assumed, and use was forecast to change as a direct function of manufacturing employment after the baseline plumbing code adjustment.

Future Industrial Process Use Factors

For industrial process use (about 30 percent of overall industrial water use), no changes in current industry-specific factors were incorporated in the forecasts. Future process use in each industry was assumed to change in direct proportion to the physical quantity of output, as measured by the industrial production index in each industry. Industrial output was indexed (1980 = 100) and was forecast to grow in relation to employment in each industry and the nationally forecast changes in output per employee. These increases in output per employee in the manufacturing sector averaged about 4 percent per year for all industries -- ranging from less than 1 percent per year in leather and petroleum products to more than 5 percent per year in electrical machinery and rubber and plastic products. Economies of scale and improvements in manufacturing process efficiencies were anticipated to continue to moderate increases in process water use due to increased output. Consequently, the rate of change in process water use was dampened to 75 percent of this rate of change in output for the traditional "wet" industries (food processing, paper, chemicals) and to 50 percent of the rate of change in output for all other industries.

Future Industrial Cooling Use Factors

For industrial cooling use (about 60 percent of overall industrial use), many reductions in water use due to recycling, etc., were estimated to have been implemented, based on the user survey. Based on interviews with industries which have and have not replaced cooling systems, and based on interviews with cooling system manufacturers, an additional 10 percent reduction was estimated to occur due to normal replacement and upgrading of cooling systems over the next 40 years.

The specific use of cooling water varies from facility to facility, and it was difficult to estimate the causal relationship between cooling water use and employment (space cooling), facilities (equipment cooling), output (product cooling), etc. For these forecasts, it was assumed that cooling water needs after the conservation adjustments would result from a combination of employment and output indicators, but that there was also a

- substantial investment in existing facilities that would make changes in use occur at a slower rate than that forecast for the weighted average of employment and output. For the baseline forecasts, the assumed weightings were 75 percent for output growth and 25 percent for employment growth, with the rate of change in demand for cooling water occurring at half this weighted average growth in each industry. The major user interviews provided the basis for this weighting and "dampening" of the demand for cooling water, but there was considerable uncertainty about long-term changes.

COMMERCIAL/INSTITUTIONAL WATER USE FACTORS

Commercial/institutional water use was estimated to have decreased slightly at individual major users but to have increased overall as nonmanufacturing employment increased by about 18 percent during the 1970s.

Overall use by the largest commercial/institutional establishments has been relatively stable: the 42 users of more than 50 MGY in 1972 together used 2 percent more water than the 46 users of more than 50 MGY in 1980. These largest users accounted for 6,374 million gallons in 1980, or one-fourth of the use by nondomestic major users, and they consisted primarily of hospitals, universities, and public facilities. As shown in Table 41, hospital water consumption increased as facilities expanded. This was offset by conservation at major universities, many of which have instituted specific water- and energy-saving programs, and by decreases in use by other institutions which were largely due to facility closings. The decline in public use was also attributable to facility closings; e.g., the transfer of U.S. Army and Navy property in Boston to industrial use and the 75 percent reduction in use at Westover Air Force Base.

Use comparisons for commercial establishments are not reliable because of incomplete data for 1972. Although the percentage change in Table 41 overstates the expansion in use by service establishments (notably offices and hotels), it is clear that new buildings and increased employment in service industries have resulted in major increases in water demand. The decline in use by wholesale and retail trade businesses was due to closings of some major city retail food stores and to less on-site processing.

Of those surveyed, 80 percent had instituted some programs of sanitary use conservation, while 60 percent had instituted some programs of cooling water use conservation. Additional surveys and updates conducted for commercial/institutional users corroborated these data but indicated that water use changes in the last two to three

Table 41. Trends in Water Use and Employment, 1972-1979

Category of User	Completed No. in Sample[1]	1980 Water Use (MGY)	Percentage Change in Water Use 1972-1980	1980 Employment	Percentage of Use by 1980 Major Users
Hospitals	53	2,244.2	15.0	67,326	9.1
Universities/Boarding Schools	26	2,597.2	-7.0	36,150	2.0
Other Inst. & Nursing Homes	16	494.2	-15.0[2]	9,869	10.6
Hotels	26	747.6	327.0[2]	7,845	3.1
Restaurants	7	90.2	23.0	1,300	0.4
Trade	15	287.4	-21.0[2]	7,850	1.1
Offices	56	1,405.2	231.0[2]	136,709	5.7
Other Commercial	27	907.5	5.0	13,801	3.6
Public	29	1,616.3	-21.0	30,401	6.5
Total Commercial/Institutional	255	10,389.8	12.0[2]	311,251	42.1

[1] Includes companies which were major users in 1972 and/or in 1980.
[2] Incomplete data for 1972 resulted in overstatement of the growth in water use.

Source: Arthur D. Little, Inc.

- years had resulted more from changes in activity levels than from changes in use practices or technology. Based on the major user interviews, it appears that there will be some future savings due to normal replacement of facilities, but that major new conservation initiatives are not likely under the baseline assumptions. For other commercial/institutional users, such as restaurants, hotels, offices, and retail stores, the interviews indicated that about 50 percent of the major users had instituted water-savings programs (e.g., flow restrictors on hotel showerheads), but that there were likely to be significant further savings as facilities and fixtures are replaced.

Future Employee-related Sanitary Use Factors

For employee-related sanitary use, it was estimated that (as in the case of industrial users) 10 percent of toilets were of the low-flow type in 1980 and that 60 percent will be of this type in 2020, resulting in a reduction of the employee-related sanitary use factor from 20 gallons per employee per day in 1980 to 17 gallons per employee per day in 2020. Use was forecast as a direct function of total nonmanufacturing employment.

Future Institutional Resident-related Sanitary Use Factors

For resident-related sanitary use, it was assumed that use will change directly as a function of institutional population, with use factors adjusted to reflect the same assumption as for other domestic use. This translated into a reduction from 90 gallons per institutional resident per day in 1980 to 79 gallons per institutional resident per day in 2020.

For Customer-related Sanitary Use Factors

For customer-related sanitary use, it was assumed that use will change as a direct function of the user population (which was assumed to grow at the same rate as the regional population) with the use factor per user to decrease by 15 percent between 1980 and 2020 due to normal plumbing fixture replacement.

Future Cooling and Miscellaneous Water Use Factors

For other commercial/institutional water uses, primarily cooling use, it was assumed that use will change as a function of space and facilities (with employment and resident/customer populations weighted equally as an indicator of space and facilities) and with the overall rate of change in water use being equal to one-half the weighted rate of change in employment and regional population. The

use factor is assumed to decline by an additional 10 percent by 2020 for conservation, as was assumed for industrial cooling use.

FUTURE NONDOMESTIC WATER USE FACTORS

Table 42 summarizes these assumed changes in nondomestic water use factors for both industrial and commercial institutional users.

NONDOMESTIC WATER USE FORECASTS

Forecasts of nondomestic water use included a base demand estimate (which included growth forecasts and the associated water use factors) and a planning range (which included assessments of the uncertainties surrounding future estimates of growth and use factors, the sensitivity of the forecasts to alternative assumptions/estimates, and the range of forecasts to incorporate 95 percent of potential uncertainties in 1990, 90 percent in 2000, and 85 percent in 2020).

BASE DEMAND ESTIMATE OF NONDOMESTIC WATER USE

On the basis of the nondomestic water use factors as described in the previous section, the forecasts of nondomestic water use associated with the adopted University of Massachusetts/Amherst control forecasts of Massachusetts growth are presented in Tables 43 and 44. In summary, Table 43 shows that, with employment increases of about 45 percent (8 percent for manufacturing, 54 percent for other), overall nondomestic water use in the 44 MDC communities will increase from 126.1 MGD in 1980 to 164.9 MGD in 2020. The 43 percent of nondomestic use that represents sanitary use (for employees, institutional residents, customers) was forecast to remain relatively stable (increasing by 9 percent) over this period as reduced use factors, resulting from the plumbing code and appliance standards, offset the effect of the moderate population and employment growth being forecast. The larger part of nondomestic use for process/cooling applications was forecast to grow substantially over the next 40 years as use factors remain relatively stable (except for increased economies of scale) and as industrial output grows substantially in most sectors.

Table 44 shows the comparable figures for the 36 non-MDC communities in the planning area.

Table 42. Forecast Changes in Future Non-Domestic Use Factors

	Growth Projection Factors	Change in Factor 1990	2000	2020
Industrial Use				
Employee-related sanitary use	Change in manufacturing employment by industry	-5%	-9%	-15%
Process use	75% of the rate of change in manufacturing output by industry for chemicals, food processing, and paper, 50% of the rate of change in output for other industries	0	0	0
Cooling use	One-half rate of change in manufacturing output and employment by industry (with output weighted 75% and manufacturing employment 25%)	-4%	-8%	-10%
Commercial/Institutional Use				
Employee-related sanitary use	Change in nonmanufacturing employment	-5%	-9%	-15%
Resident-related sanitary use	Change in institutional population	-4%	-8%	-13%
Customer-related sanitary use	Change in customers (i.e., regional population)	-5%	-9%	-15%
Process/cooling use	One-half rate of change in nonmanufacturing employment and institutional/customer population (with each weighted equally)	-4%	-8%	-10%

Source: Arthur D. Little, Inc.

Table 43. Base Demand Estimates of Growth Projections and Non-Domestic Water Use for Current Users

	1980	1990	2000	2020
Growth Projection Factors				
Manufacturing employment (000)	253.8	255.4	264.7	274.1
Nonmanufacturing employment (000)	1,002.9	1,171.8	1,267.5	1,543.1
Regional population (1980=100)	100.0	105.2	109.2	116.7
Water Use (MGD)				
1. Industrial				
Employee-related sanitary use	4.7	4.4	4.3	4.1
Process use	28.8	34.8	41.2	53.6
Cooling use and miscellaneous	28.1	29.4	30.9	34.6
Subtotal-Industrial use	61.6	68.6	76.4	92.4
2. Commercial/Institutional				
Employee-related sanitary use	17.5	19.3	19.9	22.7
Institutional resident-related sanitary use	7.2	7.3	7.2	7.3
Customer/visitor-related sanitary use	21.4	21.4	21.2	21.2
Cooling use and miscellaneous	11.6	11.8	11.5	12.2
Subtotal-Commercial/institutional use	57.7	59.8	59.9	63.4
3. Special Users and Adjustments				
Special users	5.5	5.3	5.4	5.7
Intertown transfers	1.3	1.4	1.4	1.4
Meter replacement adjustment	-	1.8	1.8	2.0
4. Total Nondomestic Use Base Estimate (not including contingencies/uncertainties)	126.1	136.9	144.9	164.9

Source: Arthur D. Little, Inc.

Table 44. Base Demand Estimates of Growth Projections and Non-Domestic Water Use for Potential Future Users

	1980	1990	2000	2020
Growth Projections				
Manufacturing employment (000)	101.8	106.3	112.9	123.4
Nonmanufacturing employment (000)	211.6	265.7	298.6	363.8
Regional population (1980=100)	100.0	105.2	109.2	116.7
Water Use (MGD)				
1. Industrial				
Employee-related sanitary use	1.9	1.9	1.9	1.9
Process use	5.5	7.0	8.7	12.5
Cooling use and miscellaneous	5.1	5.5	6.0	7.5
Subtotal-Industrial use	12.5	14.4	16.6	21.9
2. Commercial/Institutional				
Employee-related sanitary use	3.0	3.5	3.8	4.3
Institutional resident-related sanitary use	1.9	1.9	1.9	1.9
Customer-related sanitary use	2.3	2.3	2.3	2.3
Cooling use and miscellaneous	1.8	1.8	1.8	1.9
Subtotal-Commercial/institutional use	9.0	9.6	9.8	10.5
3. Special Users and Adjustments				
Transfers from MDC	-2.9	-2.6	-2.6	-2.6
Intertown transfers	0.9	*	*	*
4. Total Nondomestic Use Base Estimate (not including contingencies/uncertainties)	19.4	21.3	23.7	29.7

*Less than 0.1 MGD.

Source: Arthur D. Little, Inc.

FORECAST UNCERTAINTIES AND A PLANNING RANGE FOR FUTURE NONDOMESTIC WATER USE ESTIMATES

The principal uncertainties with respect to nondomestic water use forecasts include the forecasts of employment and output growth in different industries and the estimated changes in associated nondomestic water use factors. As noted in Chapter II, the assessment of uncertainties and the development of a planning range for water use estimates involves a four-step process:

1) The uncertainties of individual assumptions or estimates associated with use factors and growth forecasts were assessed, as was the likelihood of these alternative assumptions.

2) The combined impact of alternative assumptions of water use factors on water use was subjected to a sensititivity analysis, and this assessment included the impact of regional and national growth factors on water use.

3) A joint probability matrix (for 1990, 2000, 2020) of the likelihood of alternative base demand forecasts was constructed for domestic and nondomestic water use associated with different ranges of growth and use factor estimates.

4) Confidence estimates of water use forecast ranges and their associated probabilities were developed, based on the calculations for individual categories developed in Step 3.

Effect of Uncertain Growth Forecasts

The estimated probabilities of alternative levels of employment/output growth and their effects on forecast nondomestic water use are summarized in the lefthand columns of Table 45.

Effect of Uncertain Nondomestic Water Use Factors

The uncertainties associated with the estimates of nondomestic use factors are summarized below, and the combined effect and probabilities of these uncertainties about water use factors on nondomestic water use are summarized in Table 45.

- Alternative employee-related sanitary water use factors. The base demand estimates were based on the judgment that 75 percent of this use was for toilet flushing and that 50 percent of existing toilets will be replaced by 2020 with those now required by the

Table 45. Effect of Growth and Use Factor Uncertainties on Nondomestic Water Use in 2020

Effect of Growth Factor Uncertainties on Water Use in 2020:	Impact on Water Use Forecasts	Probability of Impacts	Effect of Possibly Higher Use Factors: Code & Appliance Standards Not Generally Followed; No Further Conservation or Improvement in Water-Use Efficiency		Effect of Most Likely Range of Use Factors: Plumbing Code & Appliance Standards Followed; No Conservation Efforts & Improved Efficiencies Using Existing Technology			Effect of Possibly Lower Use Factors: Standards Tightened, Efficiencies Improved
	→	→	+10 to +20%	+6 to 10%	+3% to +6%	±3%	-3% to -6%	-6% to -10%	-10% to -20%
		→	0.075	0.15	0.15	0.25	0.15	0.15	0.075
Effect of Possibly Higher Growth Factors: Massachusetts grows about the national rate (e.g., due to high-technology success) or nation's growth follows Census Series I forecasts.	+10% to +20%	0.075	22 to 44 0.0056	17 to 35 0.0112	13 to 26 0.0113	7 to 23 0.0187	4 to 17 0.0113	0 to 14 0.0112	-10 to +10 0.0056
	+6% to +10%	0.125	17 to 35 0.0094	13 to 27 0.0187	9 to 17 0.0187	3 to 13 0.0313	0 to 7 0.0187	-7 to +4 0.0187	-14 to 0 0.0094
Effect of Most Likely Range of Growth Factors: United States grows at Census Series I and Massachusetts continues growth performance relative to other states, equivalent to last 10 years of experience, below last 10 years.	+3% to +6%	0.15	13 to 27 0.0225	9 to 17 0.0225	6 to 12 0.0225	0 to 9 0.0375	-3 to +3 0.0225	-7 to 0 0.0225	-17 to -4 0.0113
	±3%	0.30	7 to 23 0.0225	3 to 13 0.0450	0 to 9 0.0450	-6 to +6 0.0750	-9 to 0 0.0450	-13 to -3 0.0450	-23 to -7 0.0225
	-3% to -6%	0.15	4 to 17 0.0113	0 to 7 0.0225	-3 to +3 0.0225	-9 to 0 0.0375	-12 to -6 0.0225	-16 to -9 0.0225	-28 to -15 0.0113
Effect of Possibly Lower Growth Factors: Massachusetts grows at a very low rate relative to the United States (e.g., due to high-technology exodus), or nation's growth follows Census Series II forecasts.	-6% to -10%	0.125	0 to 14 0.0094	-4 to +4 0.0187	-7 to 0 0.0187	-13 to -3 0.0313	-16 to -9 0.0187	-20 to -12 0.0187	-30 to -17 0.0094
	-10% to -20%	0.075	-10 to +10 0.0056	-14 to 0 0.0112	-17 to -4 0.0112	-23 to -7 0.0187	-26 to -13 0.0112	-30 to -17 0.0112	-40 to -23 0.0056

±10% contour ±15% contour ±20% contour

Σ probabilities within ±10% contour = 0.670
Σ probabilities within ±15% contour = 0.825
Σ probabilities within ±20% contour = 0.905

KEY
% Range of Impact
Estimated Probability

plumbing code. Since a large percentage of toilets i nondomestic facilities have flushometers, and since there remains a question as to the effectiveness of the plumbing code in governing the long-term settings of flushometers in new toilets, it was considered important to incorporate the possibility that only 2 percent of toilets would be replaced with low-flow toilets by 2020 or alternatively, that 75 percent of toilets or flushometer valves would be replaced with low-flow varieties by 2020. These alternative assumptions could change future nondomestic water use by ±3 MGD in 2020 for the 44 MDC communities.

- Alternative customer-related and other sanitary water use factors. The base demand estimates for this wate use were based on the same types of judgments about use factors as described for employee-related sanitar use above. Consequently, the incorporation of the same types of alternative assumptions which could change nondomestic use by ±2 MGD in 2020 for the 44 MDC communities was also suggested.

- Alternative institutional resident-related sanitary water use factors. The base demand estimates for thi water use were based on the same judgments as described under domestic use in Chapter II. Since this type of sanitary water use was so similar to domestic water use, the incorporation of the same levels of uncertainty in these estimates as in the domestic use estimates was also suggested. This translates into uncertainties due to use factors of ± MGD in 2020 for the 44 MDC communities.

- Alternative assumptions about industrial process wate use. The water use factors for industrial process us of water by each major user and by all minor users i each industry were assumed to remain constant for th purpose of developing base demand estimates. This type of water use was forecast to change in direct proportion to the change in industrial production ir each industry with some dampening due to improved efficiencies and economies of scale. Since there hav been some changes in water use practices and technologies in this area over the past 10 years, it appeared likely that such changes will continue. While the base demand estimates implicitly assumed that these changes will cancel each other out, a reliable planning range must incorporate the possibility that there could be a bias in these changes on the order of ±15% by 2020 (±8 MGD).

- Industrial and nonindustrial cooling use. The base demand estimates were based on the assumptions that cooling water use was 75 percent a function of output and 25 percent a function of employment, and that economies of scale resulted in changes that were dampened by 50 percent of the weighted rate of change in output and employment (plus a reduction of 10 percent for baseline conservation efforts, many of which have been implemented since 1980). To establish a reliable planning range, it is important to incorporate the possibility that economies of scale will not affect cooling water use (e.g., no dampening) and the possibility that future cooling could be equally a function of employment and output, or alternatively, completely a function of output. For the 44 MDC communities, these alternative assumptions could alter the future nondomestic water use by as much as ±7 MGD by 2020.

The probabilities of these different use factor uncertainties combining to affect water use by a different amount were estimated on the basis that the sanitary use factor uncertainties were directly linked, but independent of the linked process/cooling use uncertainties.

Combined Effect of Growth and Use Factor Uncertainties

As noted previously, the two major uncertainties affecting nondomestic water use factors were the employment/output growth factors discussed in Appendix E, and the nondomestic water use factor uncertainties described above. If these two areas of uncertainty are assumed to be unrelated, and if it is assumed that they can be translated into joint probability estimates, it is possible to estimate separately for different time periods the potential impact of both of these uncertainties on nondomestic water use forecasts, and then to estimate the likelihood of different ranges of forecast water use.

Table 45 shows estimates of the combined probabilities of variation due to both factors for 1990 and 2020 and maps out the contours and likelihoods associated with different water use ranges.

Based on confidence levels of 95, 90, and 85 percent for 1990, 2000, and 2020, respectively, the planning ranges for nondomestic water use in the 44 communities in these three years are ±11 MGD in 1990, ±15 MGD in 2000, and ±26 MGD in 2020.

Chapter 4

Unaccounted-For Water Use

INTRODUCTION

The purpose of this chapter is to document investigations of unaccounted-for water in current and potential future MDC-supplied communities. The elements of unaccounted-for water are quantified for current and potential future MDC-user communities. Projections of unaccounted-for assume a continuation of existing system management practices.

In communities served by the MDC, unaccounted-for water was approximately 106 MGD or almost 30 percent of the total water supplied to these communities in 1980. A common perception of unaccounted-for water is that it is either lost through leaks or wasted. While leaks and waste do constitute a substantial portion of unaccounted-for water in all communities, unaccounted-for water includes many useful and necessary uses of water.

ELEMENTS OF UNACCOUNTED-FOR WATER

Unaccounted-for water is influenced by many factors which include: consumer meter underregistration, revenue meter inaccuracy, unmetered public use, leakage, unrecorded connections, and accounting practices. While all of the above elements are present to some extent in all communities, their exact quantities vary significantly among communities.

LIMITATIONS ON ACCURACY OF ESTIMATES

The approach to analysis in this study is regional. While the estimates of the elements of unaccounted- for water are tabulated for individual communities, the results have limited accuracy for individual communities. The reason is that factors developed from analysis of data within the MDC study area and nationwide for elements of unaccounted-for water, are multiplied by water uses for individual communities. The results are then aggregated. While there is a high level of confidence in the composite estimate, there is no assurance that the value estimated for one community is accurate for that community.

For example, studies conducted by American Water Works Association (AWWA) committees and by individual water utilities have consistently found that unmetered public use, including water used for fire-fighting, main flushing, street cleaning, etc., comprises one to three percent of the total water delivered to a system.

For this study, it is assumed that unmetered public use currently constitutes one percent of the supply to each of the MDC user communities (except Boston where three percent is assumed, primarily to account for illegal fire hydrant openings).

From discussions with individual communities, it is found that practices regarding unmetered public water use vary. Swampscott, for example, irrigates its numerous public plantings and grassed medians to ensure a minimum of one inch per week of precipitation. Much of this water is unmetered. As a result, Swampscott's unmetered public use could be well in excess of one percent of total supply. In other MDC user communities, which perform little or no irrigation of public areas, unmetered public use is likely to be less than one percent of total supply.

Therefore, while the estimate of unmetered public use calculated for Swampscott may be too low, the value calculated for, say Medford or Malden may be too high. However, the sum of all values, representing a well-documented average for all utilities, constitutes an accurate estimate for MDC communities as a whole.

Variation in the quality of data was a further limitation on the accuracy of estimates of unaccounted-for water. The basic data report for MDC communities is the Water Services and Metering Report which consists of annual summaries of known and estimated water uses during each calendar year submitted to MDC by the communities. Data for non-MDC communities was obtained using a similar report to the State Department of Environmental Management. Although the data provided represents the best information available from the communities, they are subject to inaccuracies from stopped meters, data processing errors, and other miscellaneous sources.

It is believed that the composite estimates of accounted-for water for current, as well as potential future, users of the MDC system have the requisite accuracy to constitute a sound basis for MDC decisionmaking.

MDC REVENUE METER ACCURACY

The accuracy of the MDC revenue meters has a major influence on estimates of unaccounted-for water in communities served by the MDC. For example, a 10 percent overregistration in a revenue meter could be reflected as a 30 percent over-estimate of the amount of unaccounted-for water.

A total of 161 revenue meters measure the flow of water delivered by the MDC to the Metropolitan Water District communities. These revenue meters are of two basic

types: venturi and compound. There are approximately 110 venturi revenue meters and 51 compound revenue meters[1]. Approximately 95 percent of total water supplied by MDC to the communities passes through venturi meters, while 5 percent passes through compound meters. Venturi meters are used where flows are relatively high. Compound meters are used where flow is generally low, and significant flow variations are expected.

METHOD OF ANALYSIS

The report entitled "MDC Water Meter Study" conducted by Telemetry Systems Engineering, Inc. (TSE) in 1977 and 1978 was reviewed and analyzed. TSE tested the accuracy of 79 of the MDC's revenue meters; 57 were venturis and 22 were compounds. Those meters not tested were either inoperative or their fittings were so specialized that adaptors could not be found during the course of the TSE study. Continuing meter maintenance since the report was issued has resulted in changes in meter performance. In order to assess the impact of these changes, maintenance records provided by the MDC for all revenue meters from 1977 through 1982 were reviewed. Personnel from one of the three firms which performed the inspection and servicing were interviewed. Finally, tests of revenue meter accuracy conducted by Pitometer Associates subsequent to the TSE tests were reviewed and compared with the TSE test data.

RESULTS

Of the 57 venturi meters tested, 46 recorded more than 100 percent of actual flow. Eleven recorded less than 100 percent of actual flow[2]. Twenty-eight of the 57 meters tested measured 95 to 105 percent of actual flow and would generally be considered to be within reasonable accuracy tolerances.

For those 46 venturi meters registering more than 100 percent of actual flow, the actual flow through all of these meters during the test was 145.7 MGD; the recorded flow was 179.8 MGD.

For those eleven venturi meters registering less than 100 percent of actual flow, the actual flow through all of these meters was 49.1 MGD; the recorded flow was 37.6 MGD.

While most compound meters proved to be underregistering, the flow to the MDC communities passing through all compound meters is relatively small - on the order of 5 percent. Accuracies of the venturi meters are considerably more significant, since

approximately 95 percent of flow to MDC communities is handled by the venturis. Therefore, the balance of analysis focused on venturi meters.

For the venturi meters tested by TSE, the weighted average meter accuracy was 11.6 percent over-registration. A similar calculation was not performed for the compound meters due to the relatively small flow that they represent. However, the TSE data show that when compound meters were inaccurate, they invariably underregistered. It is estimated that if compound meters were included in the above calculation, the aggregate overregistration would be reduced to approximately 10 percent.

In an attempt to assess the current status of the revenue meters, maintenance and repair records for all revenue meters since 1977 (MDC Water Division, 1977-82) were obtained and reviewed. These records consist largely of maintenance report forms which indicate the general nature of the work performed. These reports summarize repair work performed on the venturi meters' secondary elements[3]. However, they do not contain results of accuracy tests performed following repairs nor do they reflect any work performed on the primary elements which are usually buried under roadways.

Also, despite frequent maintenance, these reports indicate that many revenue meters continue to demonstrate unpredictable and erratic behavior. Therefore, it is not possible to quantitatively assess changes in accuracy resulting from the periodic maintenance, based on these reports.

For the past several years, the Boston Water and Sewer Commission has retained the firm of Pitometer Associates to conduct leak detection programs, test large commercial and industrial meters, and test the MDC revenue meters for the city. The results of Pitometer's testing of Boston's MDC revenue meters (Pitometer Associates, Inc., 1979, 1980, 1981) were reviewed and compared to the results of TSE's study. The maintenance history of a selected group of the Boston meters was traced from the time of the TSE study to the present to determine if the accuracy of the meters improved as a result of maintenance efforts.

These meters were chosen because they were the only meters whose accuracy had been tested in the TSE Study and subsequently tested on one or more occasion by another testing organization, in this case, Pitometer Associates.

For each of these meters, a chronology was assembled from existing data. With some exceptions, those meters that evidenced inaccuracies in the MDC Water Meter Study (TSE, 1978) continue to be inaccurate.

However, no general pattern is discernible. Some meters which showed overregistration in the 1977 MDC Water Meter Study underregistered when tested subsequently by Pitometer Associates. In contrast, some meters which showed overregistration in 1977 continue to overregister.

CONCLUSION

It has been noted that relatively small errors in revenue meter accuracy have large effects on estimates of unaccounted-for water due to the way in which estimates of unaccounted-for water are derived.

When approximately half of the MDC revenue meters were tested for accuracy in 1977, it was found that, in the aggregate, these meters recorded flows approximately 10 percent higher than actual.

Since 1977, the MDC revenue meters have undergone considerable maintenance. However, despite these efforts, significant inaccuracies persist. A review of maintenance records and subsequent tests for accuracy show that merely because a particular meter is serviced, no assurance is provided that the meter is then accurate.

Up to this point, this report has focused only upon revenue meter accuracy. However, it is important to note that when, for billing purposes, quantities of water are calculated by the MDC, in many cases they are not based upon the actual meter readings. The MDC recognizes that at any particular time several meters are either out of service or highly inaccurate. It adjusts the flows up or down to reflect the best assessment of actual flow. Adjustments are made after reviewing weekly revenue meter readings, noting variances of 10 percent or greater in the recorded consumption, and checking with communities to rule out any specific reason for large consumption variations (such as broken mains, fires, stand-pipe overflows, etc.) Therefore, even though some revenue meters are inaccurate, the statistics on flow to communities served by the MDC may or may not be correct depending upon the nature of the adjustment. No attempt was made under this study to analyze MDC adjustments.

In the context of the MDC Water Supply Study and EIR, the implications of possible inaccurate revenue meters on estimates of unaccounted-for water in MDC

communities may be some cause for concern, particularly since there is a magnified relationship between revenue meter inaccuracy and unaccounted-for water estimates. Clearly, there are many unresolved questions relative to revenue meter accuracy. The MDC is currently reconstructing the 67 largest revenue meters in its system. Once this program is complete in early 1983, the readings from the new meters will be compared to readings from the existing meters so that more definitive assessments will be possible.

Ultimately, in order to gain complete assurance in the accuracy of the system of revenue meters, revenue meter flows would be combined with credible estimates of leakage from the MDC transmission and distribution system downstream of the Shaft 4 meters[4]. The total flow (revenue meters plus estimated leakage) would then be compared to the Shaft 4 meter readings.

Although the results of previous test reports on some of the MDC revenue meters have indicated significant inaccuracies, no generalized statement can be made about the current accuracy of the MDC revenue meters as a whole without a comprehensive testing program of the meters as they currently exist. For purposes of this study, it will be assumed that, in aggregate, the MDC revenue meters are accurate.

DOMESTIC METER UNDERREGISTRATION

GENERAL

For this study, domestic meters are defined as meters one inch and less in size. These meters comprise the majority (greater than 90 percent) of all meters in MDC user communities. Of these, the 5/8-inch meter is the most common, as is the meter most frequently used in residential applications. Domestic meters are also found in small commercial establishments where the nature of water use is primarily sanitary.

Domestic meters are generally classified as either reciprocating piston or nutating disk. In both cases, water flowing through a chamber causes a displacement of a piston or nutation[5] of a disc. These motions are converted to the movement of a gear train which activates a mechanism which automatically records the flow and is known as a digital totalizer.

Recent developments in domestic meter technology are gradually being incorporated into MDC communities. Virtually all new domestic meters include magnetic drives, which eliminate exposure of the totalizer and gear train to moisture and corrosion. Also remote reading meters which provide a second digital totalizer from the actual flow measuring device are becoming more

common. The latter are usually located on an exterior wall of a residence.

A further recent development is the magnetic tape meter reading system. This system enables water department personnel to connect a magnetic tape reader/recorder to the consumer's meter by means of a plug on the exterior of the residence. The meter reading is automatically recorded on tape and sent to a computer which automatically processes the data and produces a water bill. This system has not yet found widespread use in MDC user communities. However, due to its many potential advantages, it should be more widely used in the future.

Despite recent technical advances, the task of reading residential meters, in the planning area and elsewhere, is still largely a manual exercise that requires a meter reader to visit each residential water consumer about once every three to six months.

The inaccuracies inherent in water meters which are relatively inexpensive flow measuring devices will be discussed later in greater detail. However, the water meter should be viewed as only one element in the system that estimates the amount of a product delivered to the consumer and renders a bill for that product. While the meter is subject to inaccuracies, other elements of the system can, and often do, account for inaccuracies in estimating the quantity delivered.

Remote-reading meters are being installed in response to the problem of "lockouts", which have been increasing in number in recent years. In some communities, lockouts occur at 30 percent or more of all metered accounts. The result of the lockout problem is that the meter reader, generally an experienced technician, is unable to listen for leaks in the plumbing or in the service connection or otherwise inspect for the many conditions that could signal a defective or faulty meter.

Budget reductions in many communities have resulted in a reduction in the number of meter readers forcing some water departments to reduce the frequency of meter reading while maintaining the established frequency of billing. In those cases when a bill is sent but the meters not read, previous meter readings are averaged to estimate the bill.

The result of the increasing number of lockouts and decreasing frequency of meter reading is that the single, periodic contact between the water department and its consumers is occurring less often and in some cases, has been eliminated. This departure from

traditional practices is difficult to translate into a quantity of unaccounted-for water. However, it is believed that as a result of less frequent direct contact, small leaks and defective meters will not be repaired for longer periods before detection.

It is important to recognize that the primary purpose of the metering system is to raise revenue; not necessarily to compile accurate data on water usage. Every MDC user community has facilities that are metered but not billed. These facilities include public buildings, schools, churches, and health care facilities. All communities record these non-revenue meter readings. However, some communities record them with greater diligence than others. It is suspected, while not confirmed, that in some communities, water use in these facilities is not always accurately recorded simply because it is not billed. The unrecorded uses, therefore, also become a part of unaccounted-for water.

Notwithstanding the many other factors involved in accurately estimating water delivered to consumers, the meter is the single most important element. In order to assess the component of unaccounted-for water in MDC communities represented by domestic meter underregistration, a meter sampling and testing program was devised.

DOMESTIC WATER METER SAMPLING AND TESTING PROGRAM

The objective of the Domestic Meter Sampling and Testing Program was to obtain a reasonable estimate of domestic meter underregistration in a number of MDC communities. The results from individual communities were then averaged to obtain an estimate of domestic meter underregistration for all MDC user communities. Examination of previous studies indicated the absence of any documented correlation between meter age, manufacturers or other variables and meter accuracy.

The domestic meter sampling and testing program depended upon the voluntary participation of MDC user communities. The following communities agreed to participate in the program:

Arlington	Malden
Boston	Marblehead
Brookline	Melrose
Chicopee	Milton
Dedham	Revere
Framingham	Somerville
Lexington	Winchester

Three of the communities were unable to fully participate in the program because of lack of access to test equipment, personnel availability, and other constraints. However, those communities which did participate represented a broad cross section of MDC users. The domestic water use in these communities represents approximately 51 percent of total domestic use in all MDC user communities.

SAMPLING AND TESTING

The sampling and testing procedures are described in detail in a report prepared by Bechtel dated July 19, 1982 entitled Domestic Meter Sampling and Testing Program.

The number of meters selected represented approximately one meter for every thousand domestic meters in the community. Meters were randomly selected for testing, for the most part using the random number selection process provided.

The meters selected for testing were removed from service, brought to a central location, and tested on water department bench testing apparatus; or in one instance, by a private testing company. Meters were tested at three flow rates: low (¼ gallon per minute-gpm), intermediate (2 gpm), and high (15 gpm) in accordance with AWWA recommended practice (AWWA, 1973). The results were then entered on standard data forms and analyzed.

The results of this calculation for all communities are summarized in Table 46, "Summary of Results - Residential Meter Testing Program".

DISCUSSION OF RESULTS

Meter test results indicate that the total estimated meter accuracy is 94.4 percent of domestic flow. In other words, for every 100 gallons passing through the domestic meters, 94.4 gallons is metered. This amount is generally comparable to results of studies conducted by other water utilities (Tao, 1981; Hudson, 1964; Kuranz, 1942; Beenfeldt, 1965; Hutzler, et al, 1978).

As expected, there were variations in testing procedures used by the communities. These variations were a result of differences in testing equipment and operators. No attempt was made to assess the reasons for the wide variations in estimated meter underregistration between communities. However, differences in testing procedures are thought to account for some of the variation.

While individual meters will overregister on occasion, the overwhelming majority of domestic meter inaccuracies are underregistration. Marblehead's public works director stated during a discussion subsequent to the tests that, when tested in the normal course of operations, Marblehead's meters frequently exhibit the same overregistration.

APPLICABILITY OF RESULTS

A ground rule for the program was that, if a meter designated to be sampled was stopped, then that meter would not be included in the test results. This is based on the presumption that a meter that fails to register will soon be noticed and steps taken to remedy the problem.

In many respects, a meter's performance varies with flow rate. As observed in the tests, a meter may not have registered at all at the low or intermediate flow rates but may have registered at the high flow rate.

ble 46. Residential Meter Testing Program Summary

Community	Total # of Test Rept. Analyzed	Average Meter Accuracy (Percent)			Weighted Average Meter Accuracy (Percent)
		At Low Flow	At Med. Flow	At High Flow	
Arlington	12	91.2	96.3	98.1	96.2
Boston	322	79.5	95.4	98.4	94.4
Brookline	10	20.7	69.4	98.7	70.6
Dedham	8	74.1	87.5	98.9	88.5
Lexington	10	93.5	100.5	98.9	99.5
Marblehead	10	101.1	101.5	101.6	101.5
Melrose	10	45.7	98.7	100.1	93.7
Milton	10	89.4	99.2	99.5	96.9
Chicopee	13	79.4	98.0	99.5	96.5
Framingham	12	98.1	100.3	99.4	99.9
	417	Avg. 79.1	95.3	98.6	94.4

In actual service, where varying flow rates represent a continuum of values rather than three discrete rates of testing, this performance would simply result in underregistration. The flow rate would have to reach a certain threshold before the meter would move. All flows beneath this threshold would be unrecorded.

For each community, standard deviations of meter accuracy about the mean were calculated for low, intermediate and high flows. In those communities which had non-registering meters at low and/or intermediate flows, the standard deviation is inordinately high, implying that there is a large spread in the tested meter accuracies. A high standard deviation would normally imply a decreased level of confidence that the sample mean is an accurate representation of the population mean.

However, in most cases, the reason for this large standard deviation is explainable by the characteristic performance of water meters. Tested meter accuracies of less than 80 percent are rare. When a meter deteriorates to the point that 80 percent or less of the flow is measured, it will generally stop. The standard deviation is artificially high because of the meters' inability to measure low flows at accuracies of less than 80 percent. Therefore, standard statistical analyses are not always applicable to water meter data.

If, in computing standard deviations, the zero readings are discarded when they occurred at low and/or intermediate rates, the standard deviations are quite low (1 to 2 percent) suggesting a generally high uniformity of results within each town.

It must be assumed that sampling was random and that the tests were conducted as specified on proper test equipment. To the extent that these assumptions are correct, the results for each community would provide reasonable estimates of domestic meter accuracy. However, with the exception of Boston, the sample sizes were relatively small. More definitive estimates would require larger sample sizes.

In tests run by other utilities nationwide, domestic meter accuracy ranges generally between five and fifteen percent of domestic flow. On this basis, participating communities whose weighted average meter accuracy fell between 85 and 95 percent can have reasonable assurance that the results represent a good estimate.

When the individual community test results are combined, the mean weighted accuracy is 94.4 percent. This result is comparable with those of studies

- conducted by other water utilities. The participating communities represented a broad cross section of all MDC user communities. The total domestic flow represented by the participating communities comprises more than half of all domestic flow to MDC communities. On this basis, it is concluded that the resultant average is a reasonable estimate of domestic meter accuracy for all MDC user communities taken as a whole.

  The same value will also be used as an estimate of domestic meter underregistration in potential MDC user communities. An underregistration of 5.6% represents approximately 8.5 MGD of water for the currently-supplied MDC user communities, and 3.0 MGD of water for the potential MDC user communities.

NONDOMESTIC METER UNDERREGISTRATION

GENERAL

Underregistration in meters one inch and larger is also an element of unaccounted-for water. Age, deterioration, poor maintenance, and improper sizing of meters all contribute to inaccuracies in non-domestic meters. While these meters are not nearly as numerous as domestic meters, they experience relatively high rates of flow. Therefore, small or moderate inaccuracies can result in large volumes of unrecorded consumption. Non-domestic meters range in size anywhere from one to perhaps 12 inches. However, the majority of non-domestic meters in MDC communities are between one and six inches.

Three types of non-domestic meters are commonly found in MDC-user communities: displacement, compound, and turbine meters. There is no accurate accounting of either the total number of non-domestic meters or their distribution by type. However, the most common non-domestic meter type is the compound, which is actually a combination of a displacement meter and a turbine meter.

METHOD OF ANALYSIS

There is no characteristic consumption pattern for non-domestic users as there is for the smaller domestic users. For example, a university, a bakery, and an electric generating station would all be non-domestic users. Since water use patterns of large users cannot be characterized by a single curve, an analysis similar to that for domestic meters was not appropriate.

The selected approach was to acquire as many results of in-service accuracy tests as possible from commercial testing companies that had tested non-domestic meters in MDC communities. A weighted average of meter

underregistration was then calculated using the test data.

One of the few user communities having a comprehensive large meter maintenance and calibration program is Boston. Boston Water and Sewer Commission's objective is to test the meters of its 200 largest water users each year. During the years 1979, 1980, and 1981, the Boston Water and Sewer Commission through its consultant/contractor Pitometer Associates, Inc. tested 166 non-domestic meters (Pitometer Associates, 1979, 1980, 1981). On average, the meters tested during each of the three years represented approximately 30 percent of Boston's non-domestic flow.

The reports for each of these tests were reviewed and an average accuracy, in percent, for each meter was calculated. The accuracy of each meter was combined with the daily flow through that meter to obtain a "metered flow" (gallons per day) for that meter. The sum of all metered flows (gallons per day) was then compared to the sum of total flows through the meters. It was found that for the sum of all meters tested,

$$\frac{\text{Metered Flow}}{\text{Total Flow}} = 0.91$$

In addition to the results from Boston, test data was requested and received from the City of Worcester, Massachusetts. National Port-a-Test, Inc., a water meter maintenance company, conducted a pilot meter testing program for the city in 1980 (National Port-a-Test, 1980). Forty-seven non-domestic meters were tested; 34 required repair or calibration. Results showed an average as-tested meter accuracy of 88 percent.

The City of Baltimore issued a "Report on Proposed Large Meter Program" that summarized its expanded large meter program (City of Baltimore, 1979). The report delineates a maintenance and replacement program for all of the 6000-plus large meters in the system. Baltimore projected a 10-percent increase in revenue from their expanded large meter program.

The City of Hagerstown, Maryland supplied results of large meter tests and repairs for industrial meters in that city (City of Hagerstown, 1978). This work was done by Hydro-Metric Service Corp. as part of a water meter revenue analysis for meters three inches and larger. Results for years 1976, 1978 and 1980 indicated average percentage revenue loss due to meter underregistration to be 24, 19 and 17 percent respectively. Additional information from the city indicated that the meter accuracy tests were done over a short duration (minutes). On this basis, the

usefulness of their results for this analysis was judged to be very limited.

Repeated attempts were made to obtain documentation of large meter test results from Hersey Products, Inc., Dedham, Massachusetts, which manufactures and services Hersey meters. It had been thought that some MDC user communities may have contracted with Hersey to provided testing services on non-domestic meters. These attempts were unsuccessful.

RESULTS

After review of the available data, a value of 90 percent as a reasonable estimate of average non-domestic meter accuracy in MDC and non-MDC communities. This estimate is based primarily on the results of Boston's testing over the past three years. It is believed that non-domestic meters in Boston would be likely to represent a similar pattern of age, manufacturer and maintenance history as non-domestic meters in other existing and future MDC communities. Therefore, the estimate of non-domestic meter underregistration in Boston would be applicable to other existing and future MDC communities.

While the estimate of 90 percent accuracy draws heavily upon the results of one community's testing, there appears to be support for this estimate based particularly upon other data from Worcester, Massachusetts, and to a lesser extent from Baltimore, Maryland.

UNMETERED PUBLIC USE

GENERAL

Unmetered public use generally includes the following:

- water used in fighting fires;
- hydrant use for sewer and water main flushing, including blow-offs;
- hydrant use for street cleaning;
- unauthorized hydrant openings;
- distribution system losses due to main breaks; and
- water used or wasted as a result of construction of new mains or abandonment of old mains.

AWWA Committee 4450 D - Revenue Producing Water, presented a report in 1957 entitled "Revenue Producing Versus Unaccounted-for Water". This report states that unmetered use such as for fire fighting, street cleaning, and sewer flushing should be estimated, and that this estimate should not exceed one percent.

This analysis will investigate whether this estimate is reasonable and, if not, present a new estimate of unmetered public use.

METHODS OF ANALYSIS

The analysis was divided into four parts. The first part was a review of in-depth interviews conducted with water superintendents in ten MDC user communities during Phase I of this study. The interviews included questions relative to unmetered public use. In general, the towns could not provide quantitative estimates of total unmetered public use based on any reliable data. However, certain towns did provide limited data, enabling the compilations of a rough profile of unmetered public use.

Recognizing that water used in fire fighting is a significant element of unmetered public use, the second part was to contact the Fire Department of the City of Medford, Massachusetts which has been recording estimates of water used for fire fighting for some years. Records were reviewed to estimate quantities of water used by the city in fighting fires.

The third part was a review of the available technical literature on the subject of unmetered public use to identify any information which might support or contradict the conclusion drawn by AWWA Committee 4450 D.

Finally, data was solicited from additional communities through the survey of non-MDC communities conducted in Phase II (Water Superintendent Questionnaires) and by telephone interviews with selected communities. The following cities, counties, and water utilities were contacted directly by phone: Prince George's County, Md.; Fairfax County, Va; the Washington Suburban Sanitary Commission, (suburban Washington, D.C.); Montgomery County, Md.; Arlington County, Va.; and Manchester, N.H. Of the communities contacted, only Montgomery County, Arlington County, and Manchester were able to provide substantive information. Of the information provided, only Manchester was able to give detailed quantitative information on all elements of unmetered public use. Montgomery and Arlington counties were able to provide information on street cleaning uses.

RESULTS

The review of the ten MDC community interviews indicated that no single MDC community could provide reliable estimates of more than a few elements of unmetered public use. Since there is a lack of

reliable data for any one MDC community, the figures from several communities were combined to form a composite estimate. The composite estimate was then compared to the one percent figure. The results of the calculation based on community data tend to support the one percent figure.

While the technical literature on unmetered public use is quite limited, it is generally consistent in its conclusions.

A former water commissioner in the City of Philadelphia, following a study of unmetered public water use in that city in 1965, estimated the following unmetered public uses (U. Mass. Water Resources Research Center, 1975).

Street cleaning	0.080 MGD
Construction	0.129 MGD
Main Flushing	0.015 MGD
Fires	0.360 MGD
Illegal Hydrant Use	2.600 MGD
Main Breaks	0.600 MGD
Cement Lining Program	0.040 MGD
High Pressure Fire System	0.040 MGD
TOTAL	3.864 MGD

Total supply to the Philadelphia system in 1965 was 327 MGD. Therefore, unmetered pubiic use comprised 1.2 percent of total supply.

The article "Accounting for Unaccounted for Water" (Benevelli, 1978) supports the value of one percent given by the AWWA Committee and states that this value has been verified by detailed studies in several cities. Information on these studies was not available and, therefore, could not be reviewed.

A report dealing with the problem of unaccounted-for water in Hoboken, New Jersey (Stevens Institute of Technology, 1976) estimates fire department use at 0.04 percent of total flow. This town did have approximately 50 percent unaccounted-for water, but regardless, this estimate seems low.

The report entitled "Unmetered Water: The Search for Definitions" (Linsky, 1980) suggests that for cases where illegal hydrant openings are a problem, such as in highly urbanized areas like Boston, the value of unmetered public use should be estimated at two percent and possibly more for the summer months.

- The Water Usage Study (Water Resources Research Center, University of Massachusetts, 1975) reported that in MDC communities water usage for fire fighting was on the order of two percent of unmetered water. This report used information from 10 MDC communities as the basis for its estimate.

  In a study recently completed for the State of California Department of Water Resources, (Boyle Engineering Corp., 1982) water audits were conducted for three water distribution systems. For the City of Petaluma, it was estimated that unmetered city uses comprised 0.06 percent of total supply. The City of Poway estimated unmetered city uses were 0.95 percent of total supply. The Serrano Irrigation District estimated that unmetered district uses were 1.2 percent of total supply.

  The most comprehensive data obtained from any community to date has been from the town of Manchester, New Hampshire. Values by either estimate or actual measurements were given for virtually all components of unmetered public use. From an evaluation of the data, unmetered public use for the town is approximately 0.5 percent. Information was also provided on water used for street cleaning in Montgomery County, Maryland and Arlington Va. This is reported in Table 47.

  The information on the amount of unmetered public use developed from the above investigation is presented in matrix form in Table 47. Many of the blocks are not completed because of limitations in source information. However, despite these limitations, an estimate of unmetered public use was developed as a percent of metered use.

  As a result of the earlier interviews with MDC communities, contacts with other communities, a literature search, and calculations for a composite community, it is concluded that one percent of total supply appears to be an appropriate overall estimate of unmetered public use in current and future MDC communities, except Boston for which three percent of total supply is estimated.

le 47. Estimates of Unmetered Public Use (MGY)

y/Town	UNMETERED PUBLIC USE CATEGORIES							
	Fire Protection	Sewer Cleaning	Water Main Flushing	Street Cleaning	Illegal Hydrant Openings	Main Breaks	Distribution System Construction	Total Water Delivered (1980)
ington						9.0		1,743
okline						2.2		2,618
den						4.3		1,989
ford	9.0	0.8	0.8		0.5	1.8		3,286
wood		0.9		0.1		6.5		1,591
erville		2.8	2.8	0.1	1.2	5.0		3,586
neham						1.4		6,510
tham		0.5				7.9		4,209
ertown			3.0			0.4		1,728
ichester N.H.	14.2		1.1	2.0		1.4	0.4	4,234
ıtgomery . MD.				0.4				39,252
lington VA.				0.3				8,722

UNAVOIDABLE LEAKAGE - GENERAL

Unavoidable leakage is that amount of leakage which is too small to detect and/or economically repair. It is widely acknowledged that some level of leakage is unavoidable. Generally this leakage would be from joints, valves, fittings, taps, and other connections. The most frequently quoted value for unavoidable leakage is that developed by Emil Kuichling in 1897. Kuichling wrote "A discharge of one drop per second from each joint, five drops from each hydrant and stop valve, and three drops from each service pipe, including tap and unit cock, represents a fair measure of the average undiscoverable leakage in a well constructed distribution system... On this basis and with the assumption that on the average there are 50 pipe joints, 12 hydrants, 10 stop valves and 100 services per mile of distribution pipe, leakage will amount to 2,742 gpd per mile, or in round figures, from 2,500 to 3,000 gpd per mile" (Kuichling's words were reprinted in a report by U. Mass. Water Resources Research Center, 1975).

A derivative of this formula expresses leakage in terms of length of mains and their diameter. The derivative formula holds that unavoidable leakage is 250 gallons per day per inch diameter per mile of main. Given an average main size of 10 to 12 inches, the derivative formula is equivalent to Kuichling's formula. This analysis attempts to establish the validity of these formulae. In the remainder of this report, Kuichling's formula and the derivative formula are used interchangeably since they are very similar.

METHODS OF ANALYSIS

A four-stage methodology was employed. The first stage was a literature search and a series of interviews aimed at determining sources of available information. The second stage was a detailed review of the most promising sources of information identified in the first stage. The third stage consisted of an analysis of information on unaccounted-for water based on the AWWA 1981 "Water Utility Operating Data" Survey (AWWA, 1981). In the fourth stage, unaccounted-for water and unavoidable leakage in the fully supplied MDC communities was compared with the results of the AWWA survey.

The first stage included both computer aided and manual literature searches. A computer-aided literature search was performed on the "Water Resources Abstracts" and the "Engineering Index". The Technical Library of the AWWA also performed a computer-aided literature search using the National Technical Information Service

(NTIS), "Aqualine", and AWWA data banks. Manual literature searches were conducted at the Environmental Protection Agency (EPA) and Department of Interior libraries. A review of the journal articles from the New England Water Works Association from 1972 to 1980 was conducted.

Numerous telephone interviews were conducted to determine if there was any additional literature or studies dealing with unavoidable leakage. The AWWA, the Ductile Iron Pipe Research Association, and the several water utilities were contacted to discuss unavoidable leakage. The cities and utilities were Richmond, Virginia; Hagerstown and Baltimore, Maryland; the Washington Suburban Sanitary Commission; and the East Bay Municipal Utility District. The communities were also questioned to determine if they had developed any relationships between leakage and their distribution system characteristics that could be used to test the validity of the unavoidable leakage formula. Discussions were also held with staff personnel in the U.S. Department of Interior's Office of Water Research and Technology in an attempt to learn more about unavoidable leakage. The subject was also discussed with the chairman of the American Water Works Association (AWWA) Committee on Leak Detection.

Pitometer Associates was contacted to acquire information on their Water Use Block Studies (WUBS). This technique is used to quantitatively estimate the elements of unaccounted-for water in a limited sector of a water distribution system. The results of these studies were used to test the validity of the leakage formula.

The WUBS studies use the following methodology:

- A block in a water distribution system is isolated so that it is fed by only one main. A calibrated master meter is installed at the point where water enters the isolated main.

- The 24-hour consumption as recorded on the master meter and on the individual meters is recorded. The difference between the 24-hour master meter consumption and the sum of the consumer meter readings (plus any estimates of consumption for stopped meters) is calculated. This difference is unaccounted-for water. Subsequent efforts are directed at quantifying subcategories of unaccounted-for water.

- The area is acoustically surveyed for leaks using a geophone placed every few feet over the main. All leaks detected are repaired.

- The 24-hour consumption measurements are repeated. A new figure for unaccounted-for water is determined. The difference between the two calculations is said to be recoverable leakage.

- Any stopped meters are replaced with new meters and the 24-hour consumption measurements are repeated. Unaccounted-for water is again calculated. Any change is ascribed to errors in estimating unmetered consumption.

- All old meters are replaced, and the 24-hour consumption measurements are repeated. Unaccounted-for water is again calculated. The decrease in unaccounted-for water is ascribed to underregistration of consumer meters.

At the completion of this exercise, presumably all uses of water are known.

WUBS studies for two large foreign cities (Sao Paulo, Brazil and Manila, Philippines) were reviewed in Pitometer's district offices in Maryland.

The second stage of the methodology consisted of following up sources of data which showed promise during the preliminary stage of the investigation. Generally, work was limited to obtaining and reviewing articles and reports identified in the literature search, reviewing information obtained as a result of telephone interviews, and participating in follow-up meetings with firms or individuals as appropriate. Meeting were held with Water Department officials from the City of Baltimore and the Washington Suburban Sanitary Commission in an attempt to extract results from their records.

The third stage consisted of an analysis of information provided by the 1981 AWWA "Water Utility Operating Data" (AWWA, 1981) survey. Data from the New England States of Connecticut, Maine, Massachusetts, New Hampshire, Rhode Island, Vermont, as well as the states of New Jersey and New York were used for this analysis. The assumption behind this inquiry was that an upper bound for unavoidable leakage could be established by identifying those New England area water utilities having the lowest levels of total unaccounted-for water, since no matter how well a system was managed, there would always be some level of unavoidable leakage.

The fourth stage was a comparison of unaccounted-for water and unavoidable leakage for fully-supplied communities in the MDC system with the results from the AWWA survey. Similarities in both sets of data would

- allow conclusions drawn from the AWWA analysis to be applied to the MDC service area with some confidence.

RESULTS

A review of the abstracts provided by the literature searches revealed information of limited value, but where some articles were identified for further investigation, the article was obtained and reviewed under the second stage of the methodology.

In general, none of the telephone interviews provided new information or identified studies dealing with unavoidable leakage. A frequent response was that unavoidable leakage should be evaluated on a system-by-system basis, due to the fact that leakage is a function of several factors and is also very site specific. However, none of the utilities contacted had evaluated unavoidable leakage in their systems.

The review of WUBS studies provided estimates of unaccounted-for water for two case studies. For both cases reviewed, after the master meter had been calibrated, the consumer meters replaced, and all detectable leaks repaired, unaccounted-for water was still present, and comprised between 5 and 10 percent of the flow through master meters.

These results were obtained in evaluations of a non-U.S. water system. System characteristics and construction practices are likely to be different from those in the U.S. Any quantitative conclusions would have limited applicability. However, the results do suggest that despite the fact that all apparent sources of unaccounted-for water may have been identified, some level of unaccounted-for water persists. It is safe to assume that much of this irreducible unaccounted-for water results from leaks too small to detect.

The reports detailing the results of the WUBS studies did not contain data on pipe lengths. It was therefore impossible to relate the formula of 250 gpd per inch-mile to the amount of irreducible unaccounted-for water.

The second stage of the methodology, the follow-up review of data sources identified in the literature search, provided no new information which could be used to verify or dispute the leakage formula.

The results of an analysis of unaccounted-for water for each of 125 surveyed water systems (expressed in terms of gpd per mile of pipe) showed that total unaccounted-for water in 50 percent of the communities reporting was less than 3000 gpd per mile.

These results would seem to suggest that the value of 3000 gallons per day per mile of pipe stated in the literature would be a high estimate of unavoidable leakage for some communities since more than half of the water systems had under 3000 gallons per day per mile of pipe for total unaccounted-for water. However, the results are not conclusive due to the lack of independent analysis to verify this conclusion and the lack of background information on what numbers made up the unaccounted-for water figure supplied by the communities. Moreover, the data reported in the AWWA survey is occasionally inaccurate as indicated by several water systems that account for 100 percent or more of water produced; a practical impossibility.

In the fourth stage of the methodology, the results of the AWWA study were compared to 17 fully supplied MDC communities. Whereas in the AWWA survey, unaccounted-for water ranged from 12.5 to over 28,000 gpd per mile of pipe, the same calculation performed for MDC communities, showed a range of 7,000 to 52,000 gpd per mile. These values are not consistent with the AWWA survey data. These results suggest there may be differences in categories of unaccounted-for water as reported on the MDC forms and on the AWWA questionnaires. These differences and method of reporting the basic data could account for the inconsistency in the results.

If unavoidable leakage, as determined by the formula 250 gpd per in-mile is calculated for all MDC fully-supplied member communities and expressed as a percentage of total supply, the results are as shown in Table 48.

Unavoidable leakage in Table 48 ranges from 1.9 to 12.2 percent of total supply. With the possible exception of the 12.2 percent value for Lynnfield, the values seem reasonable. It is observed that there is an inverse relationship between population density and unavoidable leakage as a percentage of total supply. The cities with high population densities have the lowest quantities of unavoidable leakage when it is expressed as a percent of total supply.

When unavoidable leakage in potential future MDC users is calculated as a percent of total supply, the results are as shown in Table 49.

Table 48. Unavoidable Leakage as a Percent of Total Supply-Fully-Supplied MDC Members

Community	Percent of Total Supply
Arlington	5.3
Belmont	5.6
Boston	2.3
Brookline	4.2
Chelsea	4.0
Everett	1.9
Lexington	6.1
Lynnfield	12.2
Malden	4.5
Marblehead	9.5
Medford	2.8
Melrose	5.2
Milton	7.8
Nahant	6.8
Newton	5.1
Norwood	5.3
Quincy	3.9
Revere	3.2
Saugus	3.9
Somerville	2.5
Stoneham	3.9
Swampscott	4.8
Waltham	2.5
Watertown	3.2
Winthrop	4.9

[1] Unavoidable leakage calculated as 250 gallons per day per inch-mile of pipe.

Table 49. Unavoidable Leakage as a Percent of Total Supply - Potential Future Users

Community	Percent of Total Supply
Acton	11.8*
Amherst	7.2*
Ashland	9.5
Athol	11.3*
Avon	17.5*
Bedford	8.8*
Billerica	10.2*
Braintree	6.3
Brockton	6.3
Chelmsford	7.8
Danvers	12.0*
Dedham/Westwood	6.5
Easton	12.6
Fitchburg	4.5
Holbrook/Randolph	5.3*
Holden	13.1
Hopkinton	16.7*
Hudson	8.7
Lancaster	8.7
Lynn	2.1
Lynnfield	14.6*
Middleton	9.3
Natick	5.8
North Andover	8.6*
North Reading	12.4
Paxton	19.2*
Rutland	11.4*
Sterling	28.4*
Stoughton	9.2
Tyngsborough	No data available
Ware	12.2
Westborough	11.8
Whitman	15.2*
Wilmington	8.2*

* Indicates community where unavoidable leakage calculated by means of formula exceeds the total of all unaccounted-for water

- It is clear from inspection of Table 49 that the 250 gpd per inch-mile formula alone is an inadequate estimator of unavoidable leakage for a broad range of communities. For almost half of the communities listed in Table 49, unavoidable leakage as calculated by the 250 gpd per in-mile exceeds the total unaccounted-for water in that community. In summary, while the formula continues to be widely quoted and employed, it has not previously been subjected to critical scrutiny.

  While it appears that the traditional formula for unavoidable leakage cannot be universally applied, derivation of an alternative formula for unavoidable leakage would be extremely difficult and could not be done for this study. Rather than depending only on the length and diameter of pipe in a system, it seems likely that unavoidable leakage would have to depend on other factors, including: pipe material, system pressure, porosity of soil, and climatic extremes. Other factors could include soil and water corrosivity, and leak detectability.

  From the conclusion that current formulations for unavoidable leakage are inadequate, one might presume that the ability to quantify recoverable leakage is seriously impaired. After all, the main reason for having a category of unavoidable leakage was to deduct it from total leakage to estimate that portion of leakage which is recoverable. Notwithstanding the above, a technique has been developed which allows estimation of recoverable leakage without explicit consideration of unavoidable leakage.

RECOVERABLE LEAKAGE

GENERAL

Several communities served by the MDC have conducted leak detection and repair programs in recent years. The results of these programs, as measured by decreased water supplied by the MDC, provide a historical basis upon which to project potential savings resulting from similar programs in the future.

A "flow profile" (see Figure 12) is a summary tabulation of all known and estimated uses of water in a community. When these elements are all subtracted from the total supply to the community the element that remains is presumably potentially recoverable leakage. However, prior analysis of leak detection and repair programs in Arlington, Malden, Norwood, Stoneham, Swampscott and Watertown, indicated that the actual consumption decrease following leak detection and repair is generally less than projections of potentially recoverable leakage based on the flow profiles. The purpose of this analysis is to expand and refine the earlier calculations.

Figure 12.

Typical Flow Profile

City or Town: ARLINGTON

Population: 50,220

ALL FIGURES ARE GALLONS PER CAPITA PER DAY

1.	1978 TOTAL	98	Minimum Flow	25
2.	Less Domestic	67 31	Less 10% of 2.	7 18
3.	Less Domestic Meter Slippage	7 24		
4.	Less Commercial & Industrial & Institutional	3 21		
5.	Less Commercial & Industrial & Institutional Meter Slippage	- 21	Less 50% of 4. and 6.	7 11
6.	Less Non-Revenue Unmetered	10 11		
7.	Less Unavoidable Leakage	5	Less 7.	5
8.	Potentially Recoverable Leakage	6		6

POTENTIALLY RECOVERABLE LEAKAGE: 6.1%

The first step was to determine which MDC communities had conducted leakage detection and repair programs on their entire water distribution systems in recent years. Next, consumption data was requested from communities by using telephone interviews. Finally, the data was analyzed, with assumptions as appropriate, to develop flow profiles and assess resultant decreases in consumption.

The information required for the analysis was: (1) the total water delivered to the community distribution system by month for the year before and the year after the repairs; (2) the breakdown of the community's metered consumption into domestic, and non-domestic categories for the year before repairs; and (3) the breakdown of the miles of pipe mains by diameters. For existing MDC communities, this information was generally available from Water Services and Metering Reports or the MDC. Data was acquired from non-MDC user communities through the Water Superintendents' questionnaires, and through telephone conversations with the appropriate community personnel.

The residual unaccounted-for water for communities with the required data was calculated using a flow profile. The format of the flow profiles was altered from that shown in Figure 12, based on analysis of the traditional formula for unavoidable leakage. Therefore, the explicit category of unavoidable leakage was removed from the flow profile calculation. The remainder after all deductions for water use, previously termed "potentially recoverable leakage" has been changed to "residual unaccounted-for water." The result of this change is a decrease in the scatter of the data when plotted. Domestic meter accuracy was assumed at 94.4 percent and non-domestic meter accuracy was assumed at 90 percent. Unmetered public use was assumed at one percent of total flow except for Boston for which three percent was used.

The decrease in consumption for each community following leak detection and repairs was calculated by comparing water consumption for equal periods before and after the repairs were performed.

For all communities for which the analysis could be conducted, residual unaccounted-for water was plotted against the decrease in consumption following leak detection and repair. An attempt was then made to characterize a linear relationship between the two variables.

RESULTS

Flow profiles were computed for all towns for which data were available. The consumption data for calculating the measured decrease in average daily flow were provided by the MDC from revenue meter records. Results of calculations of residual unaccounted-for water and decreased consumption are shown in Table 50, "Summary of Leakage Repair Savings." The data is shown graphically in Figure 13, "Leakage Repair Analysis".

This analysis shows that ratios of decreased consumption to residual unaccounted-for water vary from 0.08 to 0.70. The scatter of data shown in Figure 13 and the lack of a significant correlation suggests that the conclusions from the analysis are best summarized on an aggregate basis instead of on an individual community basis. The aggregate results suggest that approximately one-third of residual unaccounted-for water as forecast by the flow profiles is in fact recoverable.

Table 51, "Effects of Leak Detection and Repair Program on Total Water Supplied", summarizes the decrease in MDC supply in the period following a comprehensive leak survey and subsequent repair of all of the identified leaks. The communities represent a cross section of system management practices and range from communities which have periodically conducted leak detection programs to those which were conducting a program for the first time in many years. The mean decrease in supply in the period following leak detection and repair was 5.7 percent.

Table 50. Summary of Leakage Repair Savings

City/Town	Residual Unaccounted-For Water (GPD)	Decrease In Average Daily Flow (GPD)
Arlington	940,500	178,000
Malden	2,364,600	329,000
Stoneham	768,600	310,000
Swampscott	940,900	141,000
Watertown	1,123,100	483,000
Canton	471,200	85,400
Littleton	508,500	351,600
Needham	483,300	200,000
Wakefield	237,000	16,700
Dedham/Westwood	1,104,000	746,000
Danvers	294,500	56,400
Reading	175,700	41,800
TOTAL	9,411,900	2,936,900

$$\frac{\text{Decrease In Average Daily Flow}}{\text{Residual Unaccounted-For Water}} = \frac{2{,}936{,}900 \text{ MGD}}{9{,}411{,}900 \text{ MGD}} = 0.31, \text{ or } 31\%$$

Figure 13.

Leakage Repair Analysis

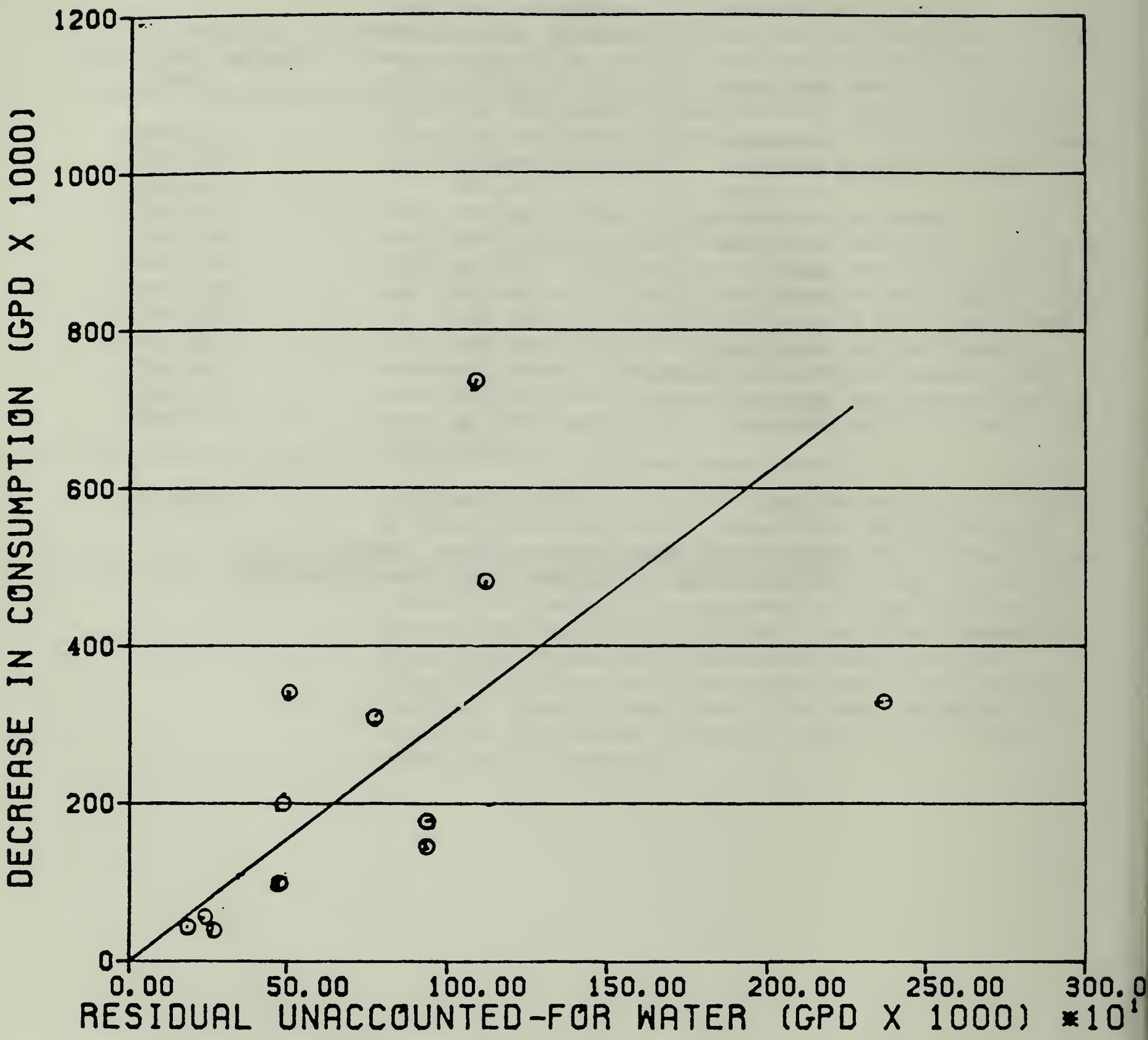


Table 51. Effects of Leak Detection and Repair Program on Total Water Supplied

MDC Community	Date of Leak Detection Survey & Repair	Average Supply in year prior to Leak Detection and Repair (GPD)	Decrease in Supply Following Leak Detection and Repair (GPD)	Percentage Decrease
Arlington	July 1980	4,772,000	178,000	3.73
Malden	Sept. 1978	6,964,140	329,000	4.72
Needham	March 1978	3,368,912	200,000	5.94
Stoneham	Nov. 1979	3,630,400	310,000	8.54
Swampscott	June 1980	2,090,000	141,000	6.75
Wakefield	Feb. 1981	2,440,000	16,700	0.68
Watertown	Oct. 1980	4,549,000	483,000	10.62
Canton	April 1981	2,819,976	85,400	3.03
Total		30,634,428	1,743,100	5.7 (avg.)

Source: Leak detection and repair reports provided by communities, and revenue meter data provided by the MDC.

OTHER UNACCOUNTED-FOR WATER

When all known and estimated uses of water are deducted from the total water supplied to distribution, the remainder is termed "residual unaccounted-for water". A portion of this residual unaccounted-for water is recoverable leakage. Historically, almost one-third of residual unaccounted-for water has been shown to be recoverable through comprehensive leak detection and repair programs. The other two-thirds is termed "Other Unaccounted-for Water". The following paragraphs will discuss elements included in that latter category.

Each water distribution system has certain unique characteristics which result in categories of unaccounted-for water which may not exist in other systems. These may include:

- illegally-tapped fire lines,
- reservoir evaporation and leakage,
- standpipe overflows,
- data processing errors,
- errors in estimates for stopped meters,
- failure to account for public use that may be metered but not billed, and
- overregistering revenue meters.

Each of these categories may exist in one or more communities, and it is safe to assume that some of these categories occur in all communities. Since there are limits on the precision of any estimate of the elements of unaccounted-for water, any error associated with estimates of the other elements is automatically allocated to the category of Other Unaccounted-for Water. A significant element of Other Unaccounted-for Water is unavoidable leakage which was shown in previous sections to be unquantifiable for this analysis.

ESTIMATES OF UNACCOUNTED-FOR WATER IN EXISTING AND POTENTIAL FUTURE MDC COMMUNITIES

A computer program was developed to compute community-by-community estimates of unaccounted-for water according to the factors derived for the MDC.

Statistics on total water supplied and estimates of domestic and non-domestic metered consumption were provided by Arthur D. Little, Inc. The resultant printouts are reproduced as Tables 52 and 53. For reasons previously explained, the estimates contained in Tables 52 and Tables 53 have limited accuracy for any given community. However, when the results are aggregated, the totals would have a considerably higher degree of precision.

le 52. Calculation of Unaccounted-For Water (Current MDC Communities)

YEAR- 1980

E	COMMUNITY	METERED RATIO	METERED			UNACC. FOR WATER (MGD)	DOMESTIC/ METER / UNDERREGISTRATION (MGD)	NON-DOMESTIC METER (MGD)	UNMETERED PUBLIC USE (MGD)	RESIDUAL UNACC.-FOR WATER		TOTAL SUPPLY (MGD)
			METERED DOMESTIC USE (MGD)	NON-DOMESTIC USE (MGD)	TOTAL METERED USE (MGD)					RECOVER-/ ABLE LEAKAGE (MGD)	OTHER / UNACC. WATER (MGD)	
**********						GROUP=FULLY SUPPLIED MDC MEMBERS						
	ARLINGTON	.750	3.180	.391	3.571	1.190	.188	.043	.048	.301	.611	4.761
	BELMONT	.863	1.861	.749	2.609	.414	.110	.083	.030	.063	.128	3.024
	BOSTON	.620	35.656	48.164	83.820	51.373	2.104	5.346	4.056	13.156	26.711	135.193
	BROOKLINE	.811	4.937	.861	5.798	1.351	.291	.096	.071	.295	.598	7.149
	CHELSEA	.930	1.795	1.344	3.139	.236	.106	.149	.034	-.017	-.035	3.376
	EVERETT	.758	2.194	4.224	6.418	2.049	.129	.469	.085	.451	.915	8.467
	LEXINGTON	.840	2.464	2.407	4.872	.928	.145	.267	.058	.151	.306	5.800
	LYNNFIELD	.738	.216	.107	.322	.114	.013	.012	.004	.028	.057	.437
	MALDEN	.827	2.981	1.514	4.495	.940	.176	.168	.054	.179	.363	5.435
	MARBLEHEAD	.760	1.557	.085	1.642	.519	.092	.009	.022	.131	.265	2.161
	MEDFORD	.469	3.530	.680	4.210	4.767	.208	.076	.090	1.450	2.944	8.977
	MELROSE	.766	1.913	.243	2.156	.659	.113	.027	.028	.162	.329	2.814
	MILTON	.684	1.697	.342	2.038	.942	.100	.038	.030	.255	.518	2.980
	NAHANT	.869	.298	.046	.344	.052	.018	.005	.004	.008	.017	.396
	NEWTON	.740	6.000	2.224	8.224	2.890	.354	.247	.111	.719	1.459	11.114
	NORWOOD	.757	1.680	1.612	3.292	1.057	.099	.179	.043	.243	.493	4.349
	QUINCY	.749	5.650	3.128	8.779	2.942	.333	.347	.117	.708	1.437	11.721
	REVERE	.593	2.342	.413	2.754	1.890	.138	.046	.046	.548	1.112	4.644
	SAUGUS	.578	1.639	.546	2.186	1.596	.097	.061	.038	.462	.938	3.782
	SOMERVILLE	.850	6.596	1.735	8.331	1.470	.389	.193	.098	.261	.530	9.801
	STONEHAM	.690	1.161	1.309	2.470	1.110	.069	.145	.036	.284	.576	3.580
	SWAMPSCOTT	.679	1.197	.139	1.336	.632	.071	.015	.020	.174	.352	1.968
	WALTHAM	.805	3.910	5.352	9.262	2.244	.231	.594	.115	.430	.874	11.506
	WATERTOWN	.637	2.268	.740	3.008	1.714	.134	.082	.047	.479	.972	4.722
	WINTHROP	.850	1.415	.355	1.770	.312	.084	.039	.021	.056	.113	2.083
SUB TOTAL			98.137	78.710	176.847	83.391	5.790	8.737	5.306	20.974	42.584	260.238
**********						GROUP=FULLY SUPPLIED NONMEMBERS						
	CHICOPEE	.805	3.885	4.467	8.352	2.023	.229	.496	.104	.394	.800	10.376
	CLINTON	.835	1.055	.546	1.601	.316	.062	.061	.019	.058	.117	1.917
	S.BOROUGH	.947	.352	.139	.492	.028	.021	.015	.005	-.005	-.009	.519
	S.HADLEY	.965	.967	1.137	2.104	.076	.057	.126	.022	-.042	-.086	2.180
	WILBRAHAM	.883	.555	.191	.746	.099	.033	.021	.008	.012	.024	.845
SUB TOTAL			6.814	6.481	13.295	2.542	.402	.719	.158	.417	.846	15.837
**********						GROUP=PARTIALLY SUPPLIED MDC MEMBERS						
)	CAMBRIDGE	.830	5.191	9.077	14.268	2.922	.306	1.007	.172	.474	.963	17.190
)	CANTON	.699	1.598	.519	2.117	.912	.094	.058	.030	.241	.489	3.029
)	NEEDHAM	.894	2.101	1.139	3.240	.384	.124	.126	.036	.032	.065	3.625
)	PEABODY	.554	3.199	1.486	4.686	3.772	.189	.165	.085	1.100	2.234	8.456
)	WAKEFIELD	.838	1.836	.202	2.038	.394	.108	.022	.024	.079	.160	2.432
)	WELLESLEY	.800	1.801	.639	2.440	.610	.106	.071	.030	.133	.270	3.050
)	WESTON	.983	.964	.156	1.120	.019	.057	.017	.011	-.022	-.044	1.140
0	WINCHESTER	.783	1.694	.331	2.025	.561	.100	.037	.026	.132	.267	2.586
0	WOBURN	.750	2.918	2.104	5.022	1.674	.172	.234	.067	.396	.805	6.696
SUB TOTAL			21.303	15.653	36.956	11.249	1.257	1.737	.482	2.565	5.208	48.205
**********						GROUP=PARTIALLY SUPPLIED NONMEMBERS						
0	FRAMINGHAM	.858	4.713	2.680	7.393	1.224	.278	.298	.086	.185	.376	8.617
0	LEOMINSTER	.855	1.913	3.366	5.279	.895	.113	.374	.062	.115	.232	6.174
0	MARLBORO	.852	2.270	1.240	3.511	.610	.134	.138	.041	.098	.199	4.12
0	N.BORGH	.904	.473	.145	.617	.066	.028	.016	.007	.005	.010	.68
0	WORCESTER	.770	7.404	12.361	19.765	5.904	.437	1.372	.257	1.267	2.572	25.669
SUB TOTAL			16.773	19.792	36.566	8.698	.990	2.197	.453	1.669	3.389	45.26
****** TOTAL ******			143.027	120.637	263.664	105.880	8.439	13.391	6.399	25.625	52.027	369.544

Table 53. Calculation of Unaccounted-For Water (Potential Future Users)

YEAR- 1980

CODE	COMMUNITY	METERED RATIO	METERED			UNACC. FOR WATER (MGD)	DOMESTIC/ METER / UNDERREGISTRATION (MGD)	NON-DOMESTIC METER (MGD)	UNMETERED PUBLIC USE (MGD)	RESIDUAL UNACC.-FOR WATER		TOTAL SUPPLY (MGD)
			METERED DOMESTIC USE (MGD)	NON-DOMESTIC USE (MGD)	TOTAL METERED USE (MGD)					RECOVER-/ ABLE / LEAKAGE (MGD)	OTHER / UNACC. / WATER (MGD)	
)	ACTON	.898	.970	.322	1.292	.147	.057	.036	.014	.013	.026	1.439
)	AMHERST	.980	1.434	1.751	3.186	.065	.085	.194	.033	-.081	-.165	3.251
)	ASHLAND	.840	.872	.107	.978	.186	.051	.012	.012	.037	.075	1.164
)	ATHOL	.814	.437	.497	.934	.214	.026	.055	.011	.040	.081	1.148
)	AVON	.870	.257	.090	.347	.052	.015	.010	.004	.007	.015	.399
)	BEDFORD	.892	.858	.541	1.399	.169	.051	.060	.016	.014	.029	1.568
)	BILLERICA	.919	2.230	.932	3.161	.279	.132	.103	.034	.003	.006	3.440
)	BRAINTREE	.748	2.577	.645	3.221	1.085	.152	.072	.043	.270	.548	4.307
)	BROCKTON	.635	6.486	2.347	8.833	5.077	.383	.261	.139	1.417	2.878	13.911
)	CHELMSFORD	.681	2.615	.699	3.314	1.552	.154	.078	.049	.420	.852	4.867
)	DANVERS	.893	1.486	.918	2.404	.288	.088	.102	.027	.024	.048	2.692
)	DEDHAM	.686	1.281	.661	1.943	.889	.076	.073	.028	.235	.477	2.832
)	EASTON	.710	.828	.301	1.128	.461	.049	.033	.016	.120	.243	1.589
)	FITCHBURG	.661	2.202	2.913	5.115	2.623	.130	.323	.077	.691	1.402	7.738
)	HOLDEN	.658	.820	.131	.951	.494	.048	.015	.014	.138	.279	1.445
)	HOLBROOK	.846	.563	.189	.751	.137	.033	.021	.009	.024	.049	.888
)	HOPKINTON	.947	.423	.117	.541	.030	.025	.013	.006	-.004	-.009	.571
)	HUDSON	.650	1.210	.213	1.423	.766	.071	.024	.022	.214	.435	2.190
)	LANCASTER	.815	.404	.041	.445	.101	.024	.005	.005	.022	.045	.546
)	LYNN	.850	8.781	4.391	13.172	2.324	.518	.487	.155	.384	.780	15.497
)	LYNNFIELD	.869	.495	.011	.505	.076	.029	.001	.006	.013	.027	.582
)	MIDDLETON	.894	.164	.137	.301	.036	.010	.015	.003	.002	.005	.336
)	NATICK	.710	2.716	.445	3.161	1.291	.160	.049	.045	.342	.695	4.453
0	N. ANDOVER	.962	1.784	.445	2.230	.088	.105	.049	.023	-.030	-.060	2.311
0	N. READING	.669	.590	.066	.656	.324	.035	.007	.010	.090	.183	.980
0	PAXTON	.864	.189	.003	.191	.030	.011	.000	.002	.005	.011	.221
0	RANDOLPH	.832	1.590	.582	2.172	.439	.094	.065	.026	.084	.170	2.61
0	RUTLAND	.899	.158	.060	.219	.025	.009	.007	.002	.002	.004	.24
0	STERLING	.839	.311	.044	.355	.068	.018	.005	.004	.013	.027	.42
0	STOUGHTON	.850	1.836	.202	2.038	.360	.108	.022	.024	.068	.137	2.39
0	TYNGSBORO	.818	.372	.071	.443	.098	.022	.008	.005	.021	.042	.54
0	WARE	.792	.601	.128	.730	.192	.035	.014	.009	.044	.089	.92
0	WESTBORO	.772	1.022	.541	1.563	.462	.060	.060	.020	.106	.215	2.02
0	WESTWOOD	.686	.689	.358	1.046	.479	.041	.040	.015	.127	.257	1.52
0	WHITMAN	.900	.538	.178	.716	.080	.032	.020	.008	.007	.013	.79
0	WILMINGTON	.770	.877	1.317	2.194	.655	.052	.146	.028	.142	.287	2.84
****** TOTAL ******			50.667	22.393	73.060	21.643	2.989	2.486	.947	5.023	10.198	94.70

PROJECTIONS OF UNACCOUNTED-FOR WATER IN EXISTING AND POTENTIAL MDC-SUPPLIED COMMUNITIES

GENERAL

Unaccounted-for water in MDC user community distribution systems comprises almost 30 percent of total water supplied to those systems. Changes in unaccounted-for water can influence the quantity of water supplied to communities. However, the extent of this influence depends upon how each element of unaccounted-for water changes. If the change results from improved metering, the community realizes increased short-term revenues, but the total water supplied or consumed is unchanged. On the other hand, if the change in unaccounted-for water results from a reduction in leakage, then total supply decreases accordingly.

How the elements of unaccounted-for water change between now and 2020 will depend upon a multitude of technological, legal, institutional, and economic factors.

"Existing system management practices" is a term applied to assumed, existing operating rules for projecting baseline conditions. The general premise underlying these rules is that existing practices and conditions will continue essentially unchanged, except in cases where a program already in place can be expected to produce some alteration of existing conditions.

Some of the major operating rules specifically related to current unaccounted-for water in user communities include:

- No new MDC-sponsored demand management programs.
- Continuation of the Chapter 805 and 286 leak detection and repair grant program for three more years (through 1985, as legislated).
- Enactment of no other major system rehabilitation programs (federal or state).
- Current maintenance programs of communities will continue without significant change over the 40-year study period.
- MDC revenue meter inaccuracy assumed to be no greater than plus or minus five percent following their rehabilitation.
- Unavoidable leakage will remain at current levels.
- Unmetered public use will remain at current levels.
- Underregistration in consumer meters in user communities will remain at current levels.

- In order to produce numerical projections, these rules must be transformed into specific assumptions for each element of unaccounted-for water. A discussion of these assumptions follows:

DOMESTIC METER UNDERREGISTRATION - ASSUMPTIONS

With certain exceptions, domestic meter under-registration is assumed to remain at 5.6 percent of total domestic use based on current estimates of underregistration.

The exceptions are those communities identified from questionnaire responses or earlier work as having aggressive domestic meter repair/replacement programs. These are:

Currently MDC Supplied	Potential MDC Supplied
Arlington	Ashland
Belmont	Athol
Boston	Avon
Canton	Holden
Norwood	Lynn
Wakefield	Rutland
Waltham	Ware
Worcester	Westwood

For these communities, domestic meter underregistration is estimated at 4.3 percent in 1990, 2000, and 2020. This value is the average of the current overall estimate of 5.6 percent, and the assumed under-registration of 3 percent under improved system management practices.

NON-DOMESTIC METER UNDERREGISTRATION - ASSUMPTIONS

With certain exceptions non-domestic meter under-registration is assumed to remain at 10 percent of total non-domestic use for the study period, the currently-estimated value.

Exceptions are communities identified as having aggressive non-domestic meter maintenance programs. These are:

Currently MDC Supplied	Potential MDC Supplied
Boston	None
Worcester	

For these communities, non-domestic meter under-registration is estimated at 7.5 percent in 1990, 2000, and 2020. This value is the average of the current overall estimate of ten percent and the assumed

underregistration of five percent under improved system management practices.

UNMETERED PUBLIC USE - ASSUMPTIONS

Unmetered public use is currently estimated as 3.0 percent of total supply to Boston, and 1.0 percent of total supply to all other communities.

For projections, the quantity in million gallons per day currently estimated is expressed as a percent of total metered use. This percent of total metered use is held constant over the study period.

RECOVERABLE LEAKAGE - ASSUMPTIONS

The Chapters 805 and 286 grant programs are to provide a total of $70 million in grants over a five year period from 1980. Approximately 5 percent ($3.5 million) is designated for leak detection, with 95 percent ($66.5 million) designated for system rehabilitation. The funds are provided by the Commonwealth on a 50/50 matching basis.

These programs are expected to have a significant effect on levels of system leakage in planning area communities. During the first two years of the grant programs, 15 of the 30 MDC fully-supplied communities received grants for leak detection and repair. The 14 communities, other than Boston, accounted for 52 percent of MDC flow to fully-supplied communities other than Boston (70 percent of flow when Boston is included).

If current trends were projected, one might conclude that during the remaining three years of the program, all MDC communities will have received leak detection grants. Perhaps a more realistic assumption might be that while additional MDC communities will receive grant funds during the next three years, there will still be some MDC communities which do not receive grants. Reasons could include lack of matching funds, a desire to avoid conditions associated with acceptance of a grant, or failure to apply or qualify.

As mentioned, fully-supplied communities (minus Boston) already having received leak detection grant funds account for 52 percent of flow to MDC fully-supplied communities. For purposes of projections, it is assumed that of the fully-supplied communities responsible for the balance of flow (48 percent) - half of these, accounting for 24 percent of the flow, will receive leak detection grant funds. The communities associated with the remaining 24 percent of the flow

- are assumed not to receive grant funds. These assumptions are summarized in Table 54.

Table 54. Assumptions-Leak Detection Grant Program

By Category	Percent of Flow to MDC Fully Supplied Communities Rep. Category
Communities Already Having Received Grants	52%
Communities Projected to Receive Funds During Next Three Years	24%
Communities Projected to Receive No Grant Funds	24%

These levels of participation will also be assumed to apply to all current MDC user communities, as well as potential future user communities.

No attempt is made to predict the specific communities which will or will not receive grants.

Of the 76 percent of flow represented by communities which are projected to receive grants, it is assumed that 75 percent will retain an outside firm specializing in leak detection, and the remaining 25 percent will use grant funds to purchase leak detection equipment or train water system employees in the use of equipment.

In 1981, Boston received $25,000 from the Chapter 805 leak detection and repair grant program. While this amount (plus the communities' matching share) would be sufficient to conduct a comprehensive leak detection program in virtually all other MDC communities, it alone is not expected to result in significant reductions in Boston's leakage.[7]

Between 1977 and the end of 1981, several communities retained an outside firm to conduct a leak detection and repair program on their entire water distribution system. For all of these communities, in the year following leak detection and repair, there was a decrease in water supplied to the communities. Based on an analysis of MDC revenue meter data, this decrease ranged between 0.7 and 10.6 percent of the previous year's flow. The mean decrease was 5.7 percent.

For those planning area communities assumed to retain an outside firm to conduct leak detection and repair, total supply in the year following leak detection and repair will be reduced by 5.0 percent. This decrease in total supply will be assumed to be entirely attributable to reduced leakage. For those communities which will choose not to retain an outside leak detection firm, the consumption decrease attributable to reduced leakage will be assumed at 2.5 percent. This is based upon the assumption which appears to be confirmed in practice, that in general, part-time programs utilizing water department personnel for leak detection and repair are not as effective as a concentrated and systematic survey conducted by a firm specializing in leak detection.

However, since 1978, Boston has funded annual comprehensive leak detection and repair programs from its own budget. By the end of 1981, approximately 70 percent of the system had been surveyed (Sullivan, 1981). These programs are responsible in part for reducing the average daily flow to Boston as shown in Table 55.

Table 55. Affects of Leak Detection and Repair Programs on Total Supplied

Year	Avg. Daily Flow (MGD)
1978	142.9
1979	137.3
1980	135.2
1981	132.2

Boston Water and Sewer Commission's (BWSC) objective is to reduce average daily flow to 120 MGD by 1986 through a combination of programs including leak detection and repair. This objective may, or may not be attained. However, in light of the results of programs since 1978 and BWSC's projected continuing appropriations for leak reduction programs, a 5.0 percent decrease in Boston's 1980 total supply by 1990 resulting from leakage reduction appears reasonable given a continuation of existing system management practices.

By 1990, Boston's recoverable leakage is expected to decrease by 6 MGD to a level of about 4 MGD as a result of ongoing leak detection and repair programs. For all other currently-supplied communities, recoverable leakage is expected to decrease by 8 MGD to a level of about 6 MGD by 1990. The decrease in Boston's leakage is expected to result from leak detection and repair

- programs funded primarily from BWSC. The decrease in leakage in other currently-supplied communities will result from a combination of state grant funds and local funds.

Beyond 1990, it is assumed that leakage levels in Boston will remain essentially constant. In the other currently-supplied communities, it is expected that there will be some regrowth of leaks. It is assumed between 1990 and 2020 that one-half of the decrease experienced between now and 1990 will recur by 2020.

OTHER UNACCOUNTED-FOR WATER - ASSUMPTIONS

As explained, Other Unaccounted-for Water includes unavoidable leakage, along with the various other categories of unaccounted-for water which are different for each community.

Unavoidable leakage is expected to remain essentially constant, assuming no major breakthrough in leak detection technology or precipitous increase in the cost of water. The other components of Other Unaccounted-for Water are largely unquantifiable and no attempt to project how these miscellaneous factors may change in future years is made; the category is held constant for the study period.

FOOTNOTES

CHAPTER 1

[1]Since this work was completed the City of Lynn has become a member of the Metropolitan Water District.

CHAPTER 2

[1]As noted earlier, age, income, water-using appliances, pools, etc., accounted for some variability. Also of suspected importance was the fact that household size and composition can change drastically over the course of a year because of deaths, marriage, divorce, births, and in- and out-moves of whole families or parts of families. These factors can drastically affect either household or per capita consumption, or both, for that housing unit for that year--even though in the analysis the same household and the same number of persons (as of January 1 of that year) are assumed for the entire year.

[2]C. W. Howe, C.S. Russell, and R.A. Young, Future Water Demands: The Impact of Technological Change, Public Policies and Changing Market Conditions on Water Use Patterns of Selected Sections of the U.S. Economy, (Washington, DC: National Water Commission, 1970), cited by North Marin County Water District, North Marin's Little Compendium of Water Saving Ideas Novato, CA: March, 1977, p. 7.

[3]V. L. Gupta and D. E. Carson, Residential Water Consumption in Reno-Sparks Nevada, Reno, NV: University of Nevada, Desert Research Institute, Water Resources Center Publication No. 41059, October 1979, pp. 20-21.

[4]U.S. Environmental Protection Agency, Office of Water Program Operations, Flow Reduction: Methods, Analysis, Procedures Examples, March 1981, Table II-2, p. 5.

[5]U.S. Environmental Protection Agency, Municipal Environmental Research Laboratory, Planning Water Supply: Cost Rate Differentials and Plumbing Permits, Cincinnati, OH: May 1978, pp. 159-160.

[6]R. L. Clouser and W. L. Miller, Household Water Use: Technological Shifts and Conservation Implications, Water Resources Bulletin, American Water Resources Association, Vol. 16 June, 1980, p. 456.

[7]D. J. Palmini and T. B. Shelton, Residential Water Conservation in a Noncrisis Setting: Results of a New Jersey Experiment, Water Resources Research, American Geophysical Union;, Vol. 18, Table II-2, Aug. 1982, p. 701.

[8]The data were supplied by Mr. T. Konen of the Stevens Institute of Technology, Hoboken, NJ. Mr. Konen is analyzing the impact of water efficient plumbing fixtures and fittings for the U.S. Department of Housing and Urban Development.

[9]r^2 values measure how much smaller, relatively in the variance, for example, in town-to-town domestic consumption when population or households are taken into account than when they are not; the values will range from ±1 when there is a high degree of correlation and 0 when there is none.

[10]U.S. Department of Housing and Urban Development, Office of Building Technology, Draft Report: Demonstration of Water Savings through Installation of Low Water-use Fixtures in Residential Buildings, prepared by Brown and Caldwell, Table III-2-1, June 1982, p. 2-2.

[11]C. F. Lawrence, Estimating Indirect Cost of Urban Water Use, Journal of the Environmental Engineering Division, American Society of Civil Engineers Table III-2, August 1975, p. 523.

[12]U.S. Department of Commerce, National Bureau of Standards, National Engineering Laboratory, Water Usage Characteristics of Household Appliances and the Potential for Water Savings, prepared by R. L. Palla for Office of Policy Development Research, U.S. Department of Housing and Urban Development Washington, DC; December 1980, p. 7-11, and Table II-11, p. 21.

[13]Exclusive 1982 Swimming Pool Industry Market Report, Swimming Pool Age and Spa Merchandise, Vol. 56, November 1982, p. 114.

[14]Ibid, pp. 17-18, and Table II-12, p. 22.

[15]U.S. Department of Housing and Urban Development, Draft Report: Demonstration of Water Savings through Installation of Low Water-Use Fixtures in Residential Buildings, Table II-2-1, p. 2-2.

CHAPTER 3

[1]Curran, MDC Water Usage Study, 1974.

CHAPTER 4

[1]Of the 51 compound meters, approximately 12 measure flows to facilities operated by the Parks or Sewerage Division of the MDC.

[2]The term "Actual Flow" refers to that flow measured by TSE's flow measuring apparatus.

[3]The term "Secondary Element" refers to the transmitter manometer, receiver, and recording device as distinguished from the primary element: the venturi tube which makes the actual measurement.

[4]Shaft 4 is located near the Sudbury Reservoir in Framingham. Meters at Shaft 4 measure flow in the Hultman and Weston Aqueducts which supply water to virtually all Boston-area MDC user communities.

[5]A motion best described as rotation with a wobble-similar to the motion of a gyroscope.

[6]Not currently supplied by MDC.

[7]Prior to the Chapter 805 program, Boston Water and Sewer Commission had already been expending in excess of $100,000 per year for outside leak detection services.

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